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PROCEEDINGS

SEVENTH MEETING, SECOND HALF, 67TH SESSION

The Seventh Meeting of the Second Half of the 67th Session of the Royal Aeronautical Society was held in the Lecture Theatre of the Royal Society of Arts, 18, John Street, Adelphi, London, W.C.2, on Thursday, April 7th, 1932, when a paper on "Wing Construction," by Mr. H. J. Stieger, was read and discussed.

Mr. C. R. Fairey (President of the Society) was in the chair.

The PRESIDENT: Mr. Stieger had every claim to be regarded as a great expert on the question of wing construction. The paper dealt with the subject in a most interesting manner, particularly as the author had introduced the quite controversial subject of the single *versus* the two or multi-spar system of construction. Mr. Stieger had had, he supposed, an unrivalled experience of wing construction, if it were regarded as covering a number of different types. Following his studies in engineering in Switzerland and at the Imperial College of Science in London, he had been concerned with Messrs. Beardmore in the construction of the "Inflexible" and the "Inverness," and from the experience gained there he had developed, and in fact invented, his particular system of Monospar construction which had attracted so much attention. The first experimental Monospar wing was built by Messrs. Beardmore. Mr. Stieger was managing director of the Monospar Company and General Aircraft, Ltd., whose first machine was flying very successfully.

Mr. Stieger then presented his paper.

WING CONSTRUCTION

BY

H. J. STIEGER, D.I.C., A.F.R.Ae.S.

Introduction

"Weight" is the key to everything that matters in aircraft construction. It is of paramount importance to performance, comfort and safety. Incidentally, it is also many a designer's excuse for any shortcoming on his machine.

Analysing the weight figures for an aircraft, one can classify them into three groups :—

1. *Weights over which the designer has no influence.*—Namely, engines and accessories, airscrews, instruments, wheels and brakes, etc. This group represents about 35 per cent. of the empty weight of a normal commercial machine.
2. *Weights over which the designer has a limited influence.*—Namely, fuel tanks and pipes, cowlings, engine controls, cabin equipment, upholstery and windows, heating, etc., which represents some 20 per cent. of the empty weight.
3. *Weights within the designer's influence.*—Namely, wings, fuselage structure, tail unit, chassis, flying controls, etc., which represent about 45 per cent. of the empty weight.

Relating these figures to the all-up weight of the aircraft and assuming a total empty weight 60 per cent. of the all-up weight, this means :—

Group	1	...	...	21	per cent.
,,	2	...	...	12	,, ,,
,,	3	...	...	27	,, ,,

of which the 27 per cent. can be reasonably split into 15 per cent. for the wing structure and 12 per cent. for the remainder.

In this paper I am dealing only with wing construction, *i.e.*, a weight item representing about 15 per cent. of the total weight, but about 50 per cent. of the weight items which are directly under the designer's influence.

There are two ways of saving weight. Firstly by careful layout in view of the aerodynamic loads and an efficient structure to transmit these loads, and secondly the extremely expensive way of saving a few ounces by filing down every bolt head and drilling lightening holes in every fitting. I shall only consider the first of these methods.

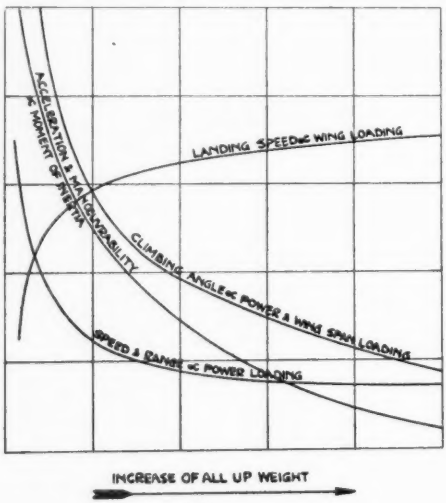
ACCELERATION & MANŒUVRABILITY
∝ MOMENT OF INERTIA
LANDING SPEED ∝ WING LOADING
CLIMBING ANGLE ∝ POWER & WING SPAN LOADING
SPEED & RANGE ∝ POWER LOADING
INCREASE OF ALL UP WEIGHT

FIG. 1.

Effect of increase in weight on performance.

It is obvious that the structural system depends upon the size and type of aircraft. The limitation of size for heavier-than-air craft has often been discussed, and opinions vary enormously, because the design assumptions for very large machines are usually very different from those for small machines. After all, a toy model aircraft can spin into the ground without getting damaged, while a larger machine built with the same load factors will smash up in a bad landing. The only reason is the increase of weight and moment of inertia, which also explains the loss of acceleration and manœuvrability the larger the size of machine. The approximate curves in Fig. 1 clearly show what we lose with increase in weight. Due to the increase of wing weight, the wing loading has to be increased, which puts up the landing speed. Due to increased power loading the speed range drops. The effect of higher wing loading and smaller power loading is a fall off in rate of climb and ratio of climbing speed to forward speed; and due to the increased moment of inertia we lose acceleration in taking off, deceleration in landing, and manœuvrability in the air.

I shall base my discussion on a group of commercial aircraft ranging from 8,000-20,000lbs. all-up weight. The first question to be settled is :—

Biplane versus Monoplane

I am afraid I cannot go into details. The question was last discussed before this Society in January, 1929, by Mr. W. S. Farren, with a resulting complete victory for the biplane.

In fairness to developments during the last few years, I feel very strongly that Mr. Farren's verdict ought to be reconsidered.

I must confess that from the time I was sitting on a school bench and listening to Mr. Farren's lectures on aircraft structures I have been arguing for the monoplane. I may, therefore, be considered a monoplane maniac !

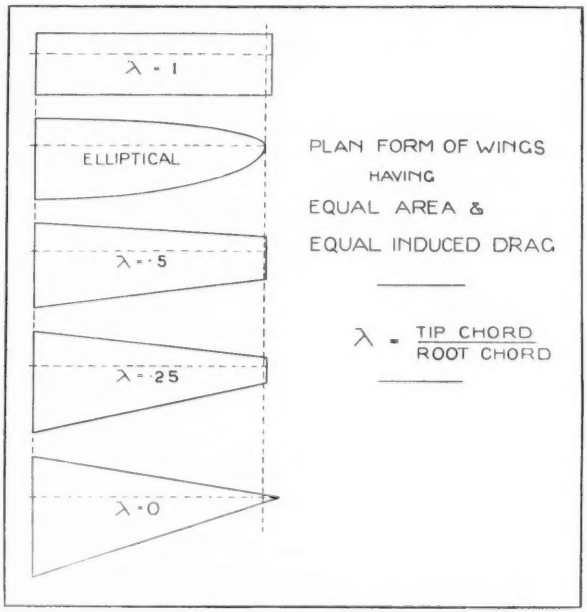

FIG. 2.

Plan form of wings on equal area and induced drag basis.

The question of biplane *versus* monoplane cannot be settled in a moment, because the type and purpose of the machine has a great influence on the solution. Also I do not think the building of two machines to identical specifications—one monoplane and one biplane—will give us a fair answer. If this controversy comes up again may I suggest that the basis of comparison is not the very much misused bogey of theoretical landing speed. Let us postulate a commercial machine, having multi-engines, when rate of climb, glide without floating, quick acceleration and small landing run should be the basis to start on.

The main arguments against the monoplane have so far been wing weight, wing flutter and loss of aileron control. To-day I think we are far enough advanced in structural and aerodynamic knowledge to get over these troubles. We can eliminate flutter and loss of lateral control over the whole flying range, and we can build monoplane wings light, if not lighter than biplane wings.

The fundamental elements of an aeroplane are the wings which enable it to fly by producing lift equal to the dead weight, and the engine which enables us to climb into the air and keep up the speed necessary to develop the wing lift. The rest of the machine expresses our inability to construct an efficient aeroplane. The undercarriage is necessary because we want a long run on a nice expensive aerodrome; the fuselage is for passenger accommodation, because we do not use the existing capacity of the wing, and to support the tail, whose function is to overcome and control an inefficient wing design.

That is, in a few words, our present stage in aircraft design.

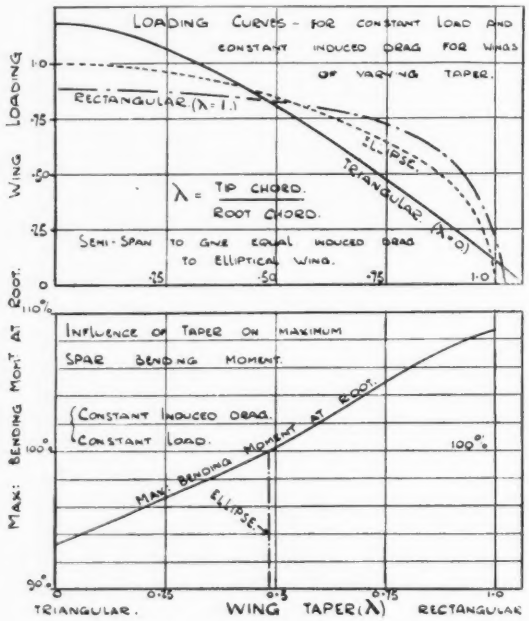

FIG. 3.

Loading curves and root bending moment for wings of varying taper ratio.

Aerodynamic Lay-out for Cantilever Wings

For practical design reasons it is necessary to have adequate spar depth if efficient spars are to be produced. Naturally the plan form and the taper in wing thickness from root to wing tip are, to a certain extent, interdependent, since the former influences aerodynamic load distribution and the latter the strength of the spars which resist that load. Then there is the effect of plan form on induced drag to consider. It can easily be shown that the best all-round proportions for a wing of given aspect ratio are obtained if the tip chord is 25 per cent.-30 per cent. of the root chord. The correct aspect ratio to adopt is again bound up with the strength question—a usual value from 7.0-7.5 seems to be the best compromise for a monoplane wing. The wing taper in turn, influences profile drag and the lift characteristics will be indifferent if the thickness/chord ratio at the wing root is much greater than 20 per cent., reducing to about 10 per cent. near the tip. Of course the greater the taper in wing thickness, the more efficient

from a weight/strength point of view are the wing spars, but one has to pay a certain price for aerodynamic efficiency.

These approximate values indicate the desirable proportions for monoplane wing structures in view of recent developments in aerodynamic theory. It is, therefore, rather surprising that so very few designers have seen fit to take advantage of them, as a cursory glance at many present-day monoplane structures will show. The reason why is not very apparent.

As regards the aerofoil sections in current use for monoplane wings, I want to emphasise a few points. It is common knowledge that for a series of aerofoil sections of varying thickness/chord ratio, constructed about the same median line, the 15 per cent. section will give the greatest maximum lift coefficient. Divergence on either side of this figure reduces the value. Furthermore, tests in a high pressure wind-tunnel at Reynolds numbers approaching full scale conditions indicate an increase in profile drag for thick sections instead of a reduction as with " thin " aerofoils.

One of the basic principles in aerodynamics is to avoid any sudden change of airflow. A large trailing edge angle to an aerofoil causes it to contradict this principle and to accelerate the stalling point by suddenly changing the direction of the air stream and helping it to break away. The C3 section, shown in Fig. 4,

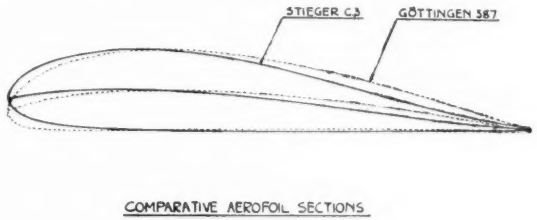

FIG. 4.

Comparative aerofoil sections—Gottingen 387 and Stieger C.3.

represents an attempt to overcome some of the disabilities which thick aerofoils experience. In its development the object was to obtain the best possible compromise between high maximum lift, low minimum drag, and reasonably small moment coefficient at zero lift. Wind tunnel experiments confirmed theoretical estimates to a remarkable degree, and full scale measurements indicated a very high maximum lift coefficient. The range of centre of pressure travel for normal design works out at .28C-.39C. It happens that this particular section was produced with a view to using it for a single spar wing and results point to the fact that the necessity of providing sufficient depth for a rear spar has had an unfavourable influence on aerofoil development.

My personal opinion is that most monoplane adherents have so far concentrated on obtaining a high maximum lift coefficient so that they can use a high wing loading figure and thereby help to reduce the wing structure weight. And this without very much regard for certain undesirable features—large centre of pressure travel and sudden stall due to discontinuity of the lift curve and resultant bad spinning characteristics—which are inherent in many high lift aerofoil sections. Once the wing weight figure is under control, I consider that there will be a growing tendency to use those sections which combine small centre of pressure travel with reasonably low drag—that is aerofoils of which the median line has a small reflex near the trailing edge. It is important to note that too great a reflex will, among other things, tend to promote roughness of operation of the ailerons.

As regards lateral control, the full cantilever monoplane has the advantage that a suitable wash-out of incidence from wing root to tip makes it possible for the ailerons to remain operative until the last possible instant. In fact with all due respect to the wing-tip slot, I consider that a judicious choice of aerofoil section and plan form, and a small aerodynamic wash-out of incidence render the slot unnecessary as a means of retaining control below the stall. It is true that the over-all lift of the wing is slightly affected, but the loss is not very great, and there will be a correspondingly small reduction in the bending moment on the wing due to this alteration in the lift distribution. With wing tip slots the large increase in lift coefficient over this portion of the wing necessitates considerable extra strengthening of the structure (increase in wing weight).

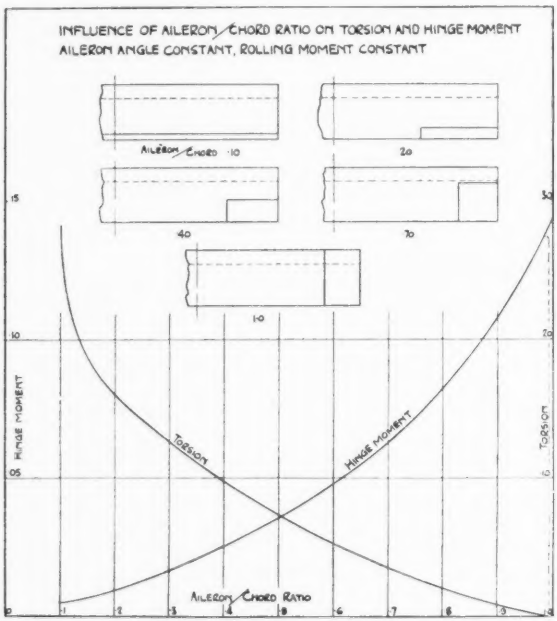

FIG. 5.

Variation of aileron/chord ratio for constant aileron angle and constant rolling moment.

Aileron Proportions

The aileron plays an important part in wing design. Its purpose is to produce a rolling moment, *i.e.*, to increase or decrease the lift of a wing, at will, without undue yaw. The time-honoured method of doing this is by a hinged flap, in which case the problems for the designer consist in coping with the hinge moment to be overcome by the pilot, and the wing torsion and deflection caused in operation.

Let us consider varying flap proportions first. The curves in Figs. 5 and 6 are not absolutely accurate, as for simplicity two-dimensional flow was assumed, but they give the trend of the variation. In Fig. 5 the rolling moment for the wing system is assumed constant and also the aileron angle, but the flap/chord ratio and length of aileron are varied. An increase in flap/chord ratio reduces

the wing torsion, but the hinge moment increases rapidly, which makes it rather impracticable for large machines.

If we vary the aileron area and also change the aileron angle accordingly, still keeping the rolling moment constant, we find (Fig. 6) that the long narrow chord flap with a large area and small angle of operation gives the smallest hinge moment and wing torsion.

There is only one disadvantage to this type, namely the maximum allowable wing twist to prevent wash-out of control.

With the long narrow type of aileron the wing has to be much more stiff torsionally to prevent loss of control.

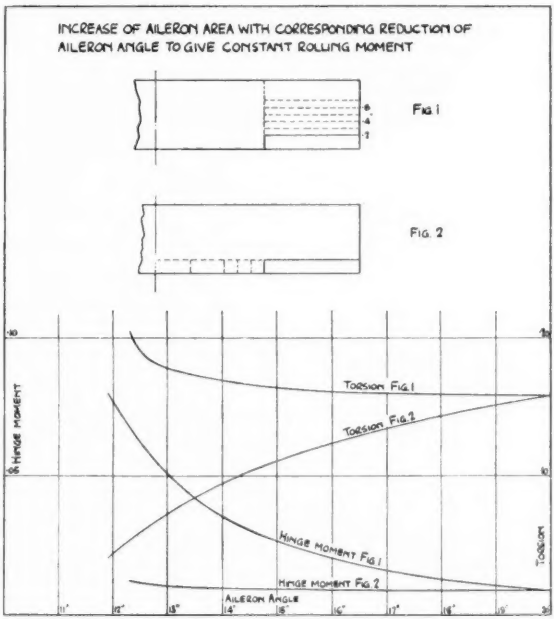

FIG. 6.

Variation of aileron area and aileron angle to give constant rolling moment.

Fig. 7 shows the reduction of effective aileron angle due to 1° wing twist. In order to get an accurate result it is necessary to make a series of approximations to get the maximum allowable twist under flight conditions, but this curve is good enough for general purposes.

Obviously, the question of aileron proportions is a matter of compromise. Generally speaking, the torsion due to aileron operation ought to be less than the maximum torsion for the particular wing section in the terminal dive case, otherwise it means extra strength and weight; for the rest it is a compromise between hinge moment (with or without aerodynamic balance) and allowable wing twist.

There is, however, one way to get round the difficulties to a certain extent, by using a triangular wing tip construction as shown in Fig. 8.

The deflection increases to a certain point and falls off again towards the tip.

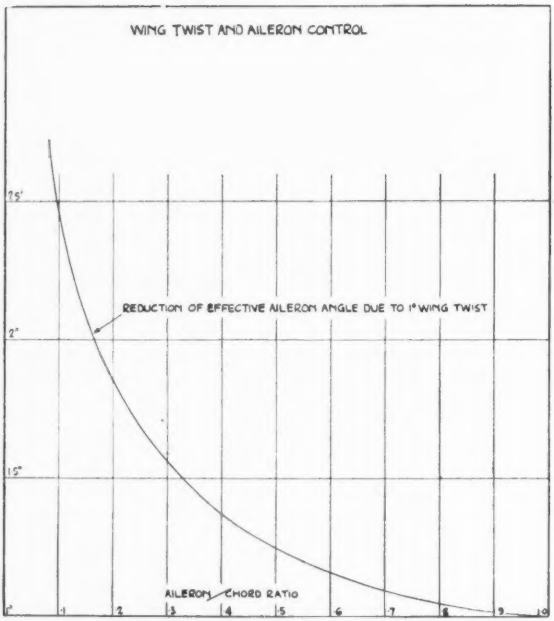

FIG. 7.
Wing twist and corresponding reduction of effective aileron angle.

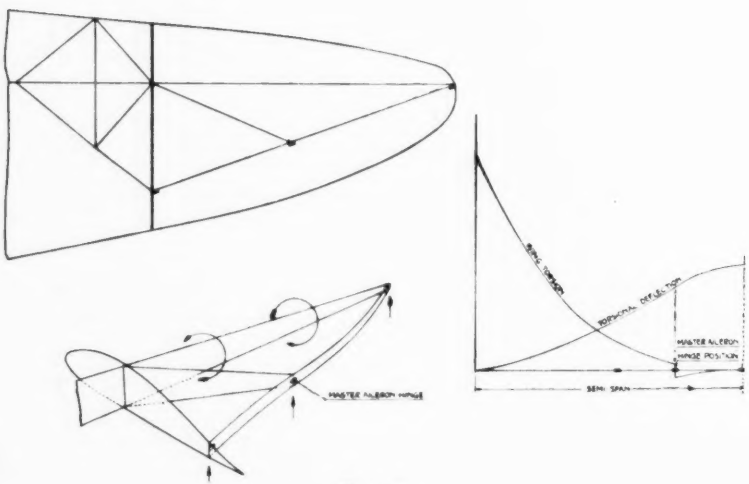

FIG. 8.
Triangular wing tip construction.

The result is that the maximum allowable twist for a wing with this type of aileron can be very much greater than for the standard type without loss of control.

There is one other point to be borne in mind when using a wing section with a reflexed trailing edge, together with differential movement of the ailerons. In this case the controls are heavier at high speed instead of lighter as in a wing of normal camber. The explanation is simple and has been confirmed by a number of recent full scale experiments.

At an incidence corresponding to maximum speed, the aileron on a reflex section has a down load instead of an up load and therefore the differential motion ought to be reversed. It also explains another fact. A fair degree of play on the aileron control was noticed at high speed when using a reflex section. What happens is that normally the joy stick is connected to the " lift " cable of the

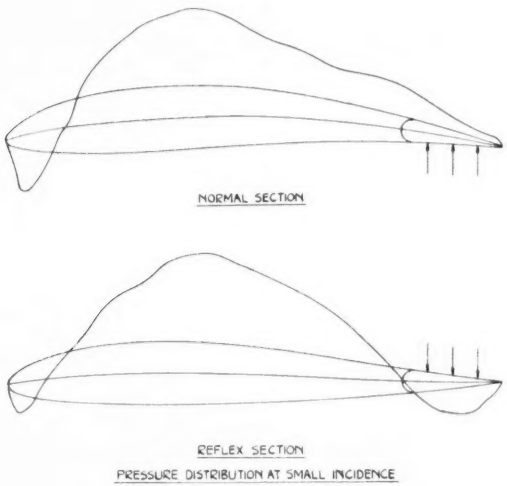

FIG. 9.

Pressure distribution at small incidence.

aileron, which tautens in straight flight due to the actual lift on the aileron, while the balance cable becomes slack. For a reflex wing, where the aileron load reverses at high speed, the lift wire becomes really the balance wire, and gets slack and you have to take up this slackness on the stick first, before the aileron can operate.

Wing Root Interference

The problem of wing root interference is important on all aeroplanes, but in no case so much as with the full cantilever monoplane. For design reasons it is not practical to mount the wing completely clear of the fuselage, either above or below, although this would produce an uninterrupted lift distribution over the whole span. With a thick wing root section and a large plan form taper ratio the flow at the wing root is very bad at values of wing incidence approaching the stall. In a high-wing monoplane, the path of disturbed flow passes unnoticed above the tail plane, in a low-wing type it tends to produce " tail-buffeting," unless one is very fortunate in the choice of tail plane position. In a biplane, the comparatively narrow chord and thin aerofoil section of the bottom wing reduces the liability to disturbed flow and the airflow off the top wing has a

very marked effect in smoothing out this disturbance, so that " tail-buffeting " is a very rare occurrence.

Experiments have been carried out on a small low-wing twin-engine monoplane by attaching light streamers at the wing root and observing the flow in a series of glides, " engine off." The degree of inefficiency of the flow was remarkable although, to the outward eye, there did not seem to be anything aerodynamically unsound about the junction of the fuselage and wing. In a normal glide, there was found a marked indication of a vortex off the trailing edge, travelling forward along the fuselage. This particular machine was eventually fitted with small auxiliary aerofoils just above and slightly behind the leading edge, between the fuselage and the wing engine cowling. The stalled flow was thereby corrected to a great extent and " buffeting " on the tail previously experienced in slow glides was eliminated.

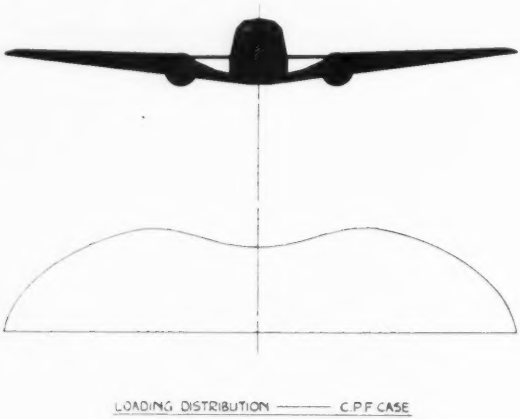

FIG. 10.
Load distribution curve.

However, it was obvious that this was only a way of remedying the evil once it had developed. The logical method of attacking the problem was to prevent the stalled flow from commencing at all. A satisfactory solution was found by reducing the wing thickness at the root, as shown in Fig. 10, and furthermore by providing a wash-out of incidence from the thickest part of the wing to the root. This involves a certain sacrifice in wing lift, but it is a case of choosing between two evils, and it is better to suffer this reduction than to lose the lift completely at a time when it is needed most.

One can summarise the fundamental points for the aerodynamic layout as follows :—

1. Weight distribution along the span obviously reduces the wing bending moment, but it increases the lateral moment of inertia for which we pay with a loss of manœuvrability; load decentralisation is really only necessary in very large machines.
2. A large plan form taper (tip chord = .2 to .3 of root chord) is very effective in reducing the bending moment without affecting the aerodynamic characteristics adversely.
3. Careful choice of wing section, tapered in thickness, but preferably with the same centre line curve to preserve conformity. The trailing edge angle of the thick sections to be kept reasonably small to prevent adverse full scale effects.

4. Best aileron proportion to give a good compromise between wing torsion, hinge moment and maximum allowable wing twist.
5. Careful design of the wing root; rather reduce the lift distribution curve slightly at the centre, than risk getting a completely uncontrolled flow.

Review of the Most Important Wing Structures

I feel I ought to describe first the best known and most characteristic types of monoplane wing structures. Some of these represent the outcome of many years' work and engineering experience, and I want to make it quite clear that my intentions are far from condemning or praising off-handedly any particular type. As pointed out earlier, the big problem in monoplane wing design besides weight is the torsional stiffness, which in many ways is largely to blame for the heaviness of present types.

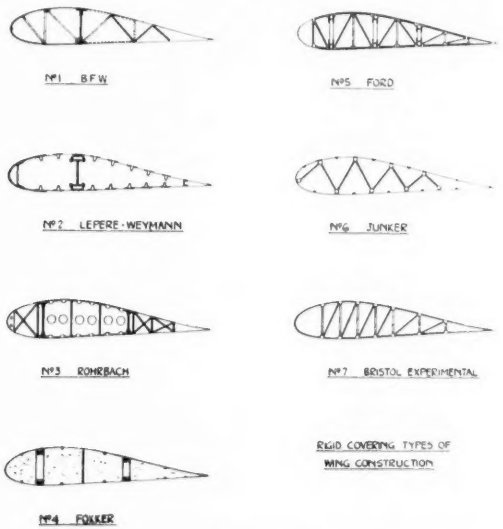

FIG. 11.

Rigid covering type of wing construction: B.F.W.; Lepere-Weymann; Rohrbach; Fokker; Ford; Junker; Bristol Experimental.

In order to make the wing stiffer most of the earlier constructions utilised a rigid covering. Fig. 11 shows seven types and the big problem here is the stabilisation of the very thin skin before it can be of service at all. Aircraft constructors who have tried to make the skin take bending loads besides torsion have had to give it up, and I think I can safely say that all of them now use it only to resist torsion and dragloads.

No. 1, *B.F.W.*—Duralumin wing construction. Single spar. Stiff nose covering forming a closed box in conjunction with the spar to resist torsion and drag loads. The single spar is in its most efficient position at the maximum ordinate of the wing section and well stabilised laterally.

The system was originally developed in wood for glider construction and proved to be very satisfactory under these design conditions (small wing loading and large span). Then Messerschmitt produced his metal version for power driven aircraft. It was successful on small types but, as the size increased,

trouble was experienced; *i.e.*, the skin crinkled and it was found necessary to stabilise the nose portion of the wing to a very much greater extent than hitherto with a multiplicity of ribs. In the case of the largest machine, it was even necessary to incorporate a second spar over the root portion where the maximum torsion occurred ($1\frac{1}{2}$ spar wing) and the metal covering extended as shown in Fig. 11, No. 1. The rear spar contributes very little to the bending strength and its chief function is to complete the shear panel.

I have studied a number of tests carried out by the B.F.W. and D.V.L. organisations and the remarkable point is that the torsional stiffness falls off rapidly under increasing load. On a wing designed to a load factor of 4W the deflection over the interval 3W-4W was 50 per cent. greater than from zero to 1W. Only in the preliminary loading stages (up to 1/10 of the design load) was a state of true shear obtained. Above this value local crinkling started to develop, in spite of careful stabilisation of the skin, due to the change over from pure shear to a system of "tension fields." The torsional deflection increased rapidly with increasing load once the "tension field" system was established, and at the design figure had reached a value twice the theoretical estimate (calculated on the thin-walled tube theory). It is interesting to note that in actual flight the deflection of the wing under pure bending is enough to start crinkling of the skin, so that it is predisposed to the formation of tension fields even before any appreciable torsion is applied.

No. 2, Lepère—Weymann.—Duralumin construction, single spar, skin stabilised by longitudinal stringers. In this system the amount of material to stabilise the skin is very much greater and the shallow rear portion of the wing is not efficient in torsion.

No. 3, Rohrbach.—Duralumin construction, two spars connected by a top and bottom panel so forming a rectangular box. Nose and trailing edge are made up separately and take no loads. Here again the difficulty is that the main loss of weight is in stabilising the skin, and in the more recent Rohrbach designs this rectangular box has been replaced by one almost square in section, in order to reduce the skin area.

No. 4, Fokker.—All wood construction. Probably one of the most successful full cantilever wings, just because the wooden covering is thicker and more stable in itself and needs very much less local stiffening. After all the Fokker wings are lighter in spite of the fact that wood is heavier on a weight/strength basis than duralumin.

Nos. 5, 6 and 7 show the Ford wing, the Junkers and Bristol experimental wings. They rely upon the metal covering for torsional stiffness, but they differ in the arrangement of the spars.

The Ford wing has three main spars of the ordinary Warren girder type.

The Junkers wing uses the characteristic pyramid shear bracing with a number of tubular spar booms. On the G.38 the multi-spar construction was such that the three spars situated in the vicinity of maximum depth of the wing section were designed to take the aerodynamic load. The rest were more in the nature of light stringers to stabilise the covering, so that there was a distinct tendency towards the idea of a single spar.

The Bristol wing is of a type similar to the Ford except for an increased number of spars.

If the load distribution on the two spars is difficult to calculate in the structure in Nos. 1 and 4, it is very much worse in Nos. 5, 6 and 7, because the spars are not only connected by the skin, but also by a system of shear bracing, and I suggest that it must be practically impossible to calculate the accurate load distribution on the spars under different flying conditions correctly without an extensive series of tests.

The tendency to use the standard fabric covering in connection with the structure which is made torsionally stiff in itself has only come into the foreground during the last few years.

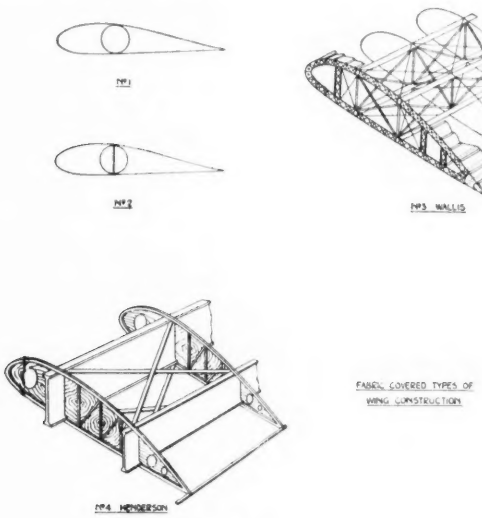

FIG. 12.

Fabric covering type of wing construction: Henderson; Wallis.

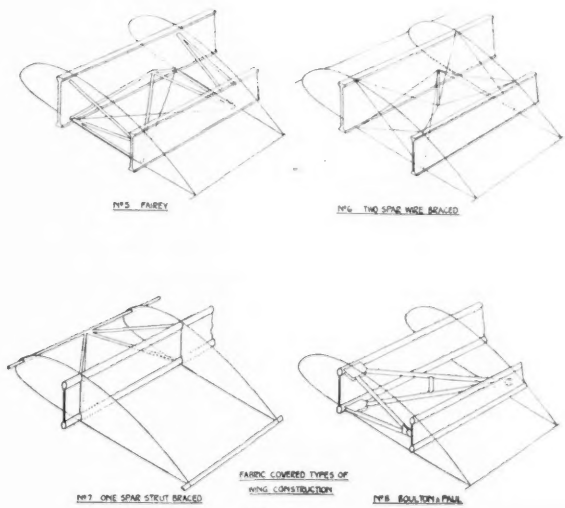
No 5 FAIREY
No 6 TWO SPAR WIRE BRACED
No 7 ONE SPAR STRUT BRACED
FABRIC COVERED TYPES OF
WING CONSTRUCTION
No 8 BOULTON & PAUL

FIG. 13.

Fabric covering type of wing construction: Fairey. Two-spar wire braced; One-spar strut braced; Boulton and Paul.

No. 1.—Tubular spar. Because of the very thin walls the spar requires numerous diaphragms. A tube in itself is inefficient for bending, and if the spar deflects due to drag this may cause crinkling of the fabric at the trailing edge. The remarks on the B.F.W. system apply equally well in this case.

No. 2.—Single spar plus tube. This type is better in bending, but if the tubular part is made just strong enough to take the torsion, it will be found that the torsional deflection is too great.

No. 3, *Wallis.*—Square box with either bracing wires or shear struts. If bracing wires are used in the top and bottom panels, the top panel will get slack under bending loads, and therefore inefficient for torsion. The bottom panel will take a certain amount of the tension load in addition to the normal torsion loads. If shear bracing struts are used, then additional heavy loads are put up in these members due to bending.

The best practical example of this type of construction occurs in the Breda 32 (see *Flight,* April 1st, 1932). The box portion is strut braced throughout and is a case in point for illustrating a multiplicity of points and fittings. A complete metal covering, however, is used as well which is a proof of comparative inefficiency in resisting torsion of the internal framework. The previous machine of this type had metal covering over the nose portion of the wing alone and trouble arose from the fact that the wing twisted unduly under aileron loads. The Breda 32 has a light rear spar and is completely metal covered.

No. 4, *Double Drag Bracing.*—Has often been used in the past, but is not efficient. It is in principle similar to No. 3 except for the rectangular cross section. If torsion is applied halfway along the span, then the deflection of the outside portion is greater than at the point of load application, *i.e.,* the wing portion outside is actually distorted due to the loads set up in the four flanges, and therefore the total torsional deflection is great.

No. 5, *Fairey.*—A system of compression pyramid struts with wire bracing in the bottom panel with two wing spars. Due to the fact that the system is unsymmetrical, the torsion and drag deflections are not independent, *i.e.,* a plain drag produces a torsional deflection as well as a deflection on its own account and a pure torsion produces in addition a drag deflection.

No. 6, *Two spars with tension pyramids.*—The principle is similar to No. 5, except that the system is symmetrical, twice the number of pyramids are used and compression struts are replaced by tension members.

No. 7.—Single spar with compression pyramids forward of spar with apices located on the leading edge.

No. 8,,*Boulton and Paul.*—Two spar wing with strut pyramids on the rear side of the front spar. The apices being located along the line of the rear spar.

Summary.—Most of the early types used the skin for resisting the torsional stresses. The main difficulty here is the stabilising of the skin which increases the weight considerably With metal coverings the large number of rivets required makes for expense and is difficult, if not impossible to inspect. As far as the fabric covered wings are concerned, only a few have been successfully tried out. Generally where a compression strut system is used to take torsion loads, the wing tends to become as heavy as when using rigid skin.

Efficiency of Structure and Practical Design Considerations

Multi-spar versus Single-spar

Efficiency of a structural member on a strength/weight basis depends primarily on the length of the path of transmission of load before it is equilibrated, on the load in the member, and on the stress developed. Let us consider these items separately in relation to wing structure.

(*a*) *Length of Path of Transmission of Load.*—On theoretical grounds the multi-spar wing ought to be the lightest since the aerodynamic loads are all

taken to the fuselage by the shortest possible path. In a single spar wing the load first has to reach the spar by way of cantilever ribs. If in the multi-spar wing the spars are close enough together, no ribs are required—a corrugated sheet covering will serve the double purpose of resisting torsion and transferring loads to the spars as in the Junkers system.

(*b*) *Loads in Members.*—For simplicity let us consider a two-spar system as opposed to a single spar system for a machine the size of the Fokker F. VII.A. For the purpose of quick comparison I am using a formula to give the ideal spar weight (Duncanson, *Flight* Engineering Supplement, March, 1929). The actual spar weight works out at about 178 per cent. of the ideal, which is a shrewd blow at our design capabilities. Taking this relative figure the spar weight for the two-spar wing weighs approximately 40 per cent. more than the single spar type under similar loading conditions. The gain of the single spar construction lies partly in being able to place it at the deepest part of the wing section and partly from the fact that in the two-spar type, one spar is always partially idle because of the centre of pressure travel.

(*c*) *Developed Stress.*—Wherever compression loads have to be resisted in a structural member, the moment of inertia of the section and the degree of stability (*i.e.*, L/K ratio) are of primary importance. Referring to the multi-spar wing, it is obvious that due to the relatively small moment of inertia of each individual boom, all the spars must be stabilised at short intervals. This necessitates an elaborate system of cross bracing as in the Junkers, Ford and Bristol types. This bracing, with its multiplicity of joints and fittings at once accounts for the apparent saving in weight due to the elimination of wing ribs. Added to this there is the difficulty of performing an accurate calculation on the structure so that the weight is increased and the stress correspondingly reduced to allow for the ignorance factor.

It can be roughly stated that for a wing spar, 72 per cent. of the weight is in the booms and 28 per cent. in the shear bracing. In theory, the booms should be 86 per cent. and the webs 14 per cent., but in practice the inefficiency of the shear bracing is so great that the figure can never be realised. A very thin sheet would suffice if it were not for the large amount of stabilisation which would be necessary to make it function. The greater the number of spars, the more extra weight has to be put into the shear bracing. This helps to explain the difference between ideal and actual spar weight previously stated.

As regards the spar booms, the ideal would be a tube tapered in diameter and gauge thickness. In practice the solution is to have a tapered form of boom. Laminated plates can be arranged for instead of using a tapered member, but, as a type, such spars are more expensive to construct, due to the large number of rivets required, since these must be closely spaced to be efficient.

Reverting again to the multi-spar and single spar comparison, a further important point is the number of wing root fittings required as opposed to the two necessary in the single spar type. Furthermore, undercarriages and wing engine mountings (*i.e.*, any concentrated load) entail a frame to spread the load to the spars in the multi-spar type as opposed to a simple two-bolt connection.

The next important point is the subject of strength calculation. Of recent years, we have tended to become proud of our accurate methods and of our strain energy theories. In doing so we sometimes lull ourselves into a sense of false security.

In the case of the multi-spar wing, let us apply the load proportionately to each spar and assume that we have made the spars as efficient as possible regarded as separate units. That is, they all develop approximately the same stress at the design load. Then we find that, since spar deflection is proportional to spar depth as well as to the proportion of load supported, the wing section will tend to distort. Therefore we must have spar inter-bracing to maintain the wing section. But in doing this, we restrain the more shallow spars

from taking their share of the load and the deeper ones will take a larger proportion and develop a correspondingly high stress. It is practically impossible to calculate for any loading condition accurate loads for a multi-spar system in conjunction with spar inter-bracing and a rigid covering. In a single spar wing, we know the loads have to go through the spar since there is no alternative.

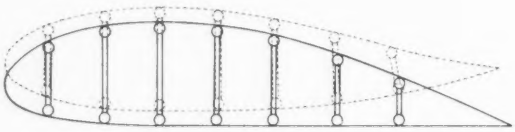
DISTORTION OF MULTI-SPAR WING UNDER LOAD
ASSUMPTION :- EQUAL MAXIMUM STRESS DEVELOPED IN EACH SPAR
DEFLECTION THEREFORE PROPORTIONAL TO SPAR DEPTH

FIG. 14.
Distortion of multi-spar wing under load.

As an example, in one of the most successful two-spar wing constructions with a rigid covering designed, not by a theorist, but by a practical engineer, the rear spar was stiffened up to comply with certain government regulations. The result was two cases of wing failure in the air.

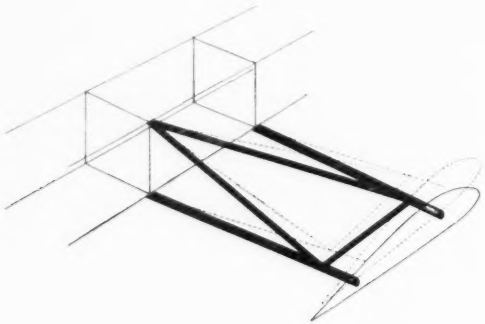

FIG. 15.
Distortion of braced monoplane wing.

The reason lies in the fact that the rear spar being stiffened, it deflected less under load than the front spar, the angle of incidence increased accordingly, increasing the load progressively until the breakage occurred.

Another instance. A two-spar braced wing, with two bracing struts unsymmetrically placed, the rear strut being in line with the rear spar, the front strut forming a substantial angle with the vertical plane through the front spar.

If the two struts are designed to the same assumptions, *i.e.*, developing approximately the same stresses, it is obvious that the front spar will deflect more than the rear spar, increasing again the incidence of the wing. The structures may be perfectly all right under static test, but in the air the distribution of load between the spars is not constant, but varies with the deflection and deformation of the wing. Quite a number of wing and tail failures can be attributed to this.

Rib Design

It seems to be the obvious thing to suppose that the rib structures of a single spar wing must necessarily be heavier than in the case of a multi-spar wing. I thought so, too, until I was in a position to compare actual weights for each type. In the case in question, two ribs were selected, both of normal

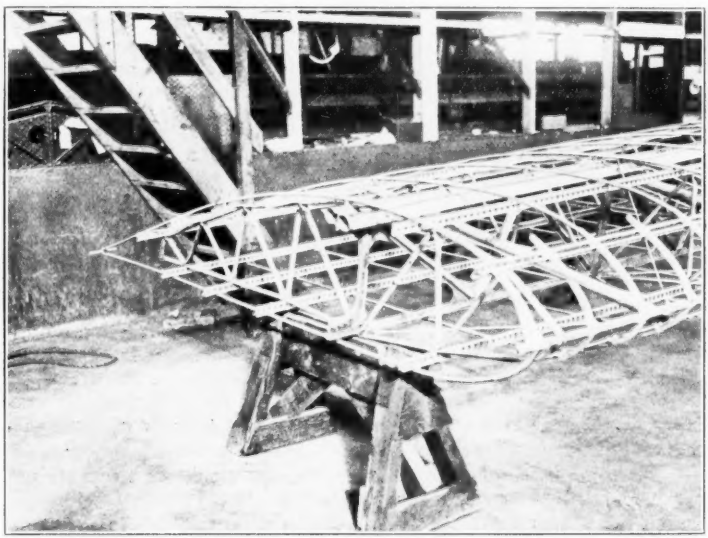

FIG. 16.
Stringer type construction.

construction and made of duralumin. The first was for a large two-spar biplane wing and the second for a Monospar Wing Fokker F. VII.A. Both ribs were of approximately the same chord and carried about the same load. The two rib weights were within $\frac{1}{2}$oz. (or 2 per cent.) of each other in spite of the fact that the biplane rib had a 12 per cent. thickness chord/ratio and the single spar an 18 per cent. value. The deflection at the trailing edge of the Monospar rib under the design C.P.B. load was only 0.6in.

On this basis against all theoretical reasons and scientific arguments the rib weight in a single spar wing is in general not heavier than for a two-spar wing.

I would like to make a further point. In very large and deep section wings, the shear bracing of the ribs becomes very inefficient and it becomes more profitable to change over to a stringer system with a comparatively small number of bulkhead ribs. Over these, longitudinal stringers are run and these in turn support unbraced fabric formers. The size of aircraft where this stringer

system becomes lighter than an independent rib system is from 800 sq. ft. area upwards.

Wing Covering

The exponents of rigid wing covering are inclined to laugh at the old-fashioned fabric system and to say that it is not an engineering job. Yet one of the most successful exponents frankly admitted that the real reason was that they were forced to use a rigid skin to obtain the necessary torsional stiffness.

A metal covering with its innumerable rivets is very expensive and impossible to inspect efficiently. Also these rivets have a nasty habit of tearing out of the very thin metal under vibration. As for the risk of fire, there is no advantage, since if petrol is present on the wings, the thin covering burns like paper.

As far as I am concerned, I can only say that if fabric is good enough for our fastest fighters it is good enough for commercial machines. It is certainly very much cheaper, easy to repair and stands up very well to all climatic conditions. Incidentally, it is much lighter than any contemporary covering as the following weights show:—

	lbs. per double sq./ft. of wing area.	Per cent. of wing weight.
Three-ply covering painted	.5-.6	25
Dural .3 mm. corrugated covering ..	.45-.6	23
Fabric doped	.19-.2	9

If a wing weighs 15 per cent. of the all-up weight and the pay load is 20 per cent. the difference between fabric and metal covering means 2.25 per cent., or 11 per cent. of the pay load.

Summing up the controversy between multi-spar construction and single spar, it is my personal opinion that the single spar wins. It is some 30-40 per cent. lighter and it is definitely much cheaper to construct. We can perform calculations to a sufficiently accurate degree and in the actual construction the designer has less chance of wasting weight on a large number of small members and fittings. Personally I have come to the following conclusions:—

The fewer the structural members the less you are liable to waste unnecessary weight and the better your chance to calculate your wing for the load conditions as they occur in the air.

Use a single spar, well stabilised laterally, with a system of torsion bracing, preferably tension members and fabric coverings. You will find a wing built on these lines lighter and cheaper than anything else. I have tried to incorporate these ideas into the Monospar system.

The Monospar System

A few years ago the aircraft world was very excited about the problem of wing flutter and of loss of aileron control. The terminal speeds of aircraft had increased rapidly to the region of the critical value for standard biplane wing structures, and certain cantilever monoplanes produced at that stage had the bad habit of suffering reversal of aileron control. The only ready remedy seemed to be to increase the number of spars and use therefore a rigid wing covering in conjunction with them. When the Air Ministry ordered an experimental single spar wing with fabric covering nobody seemed to take it seriously, yet to-day this type has been proved and may conceivably become the fashion. I want to briefly describe the Monospar wing system, which is a single spar fabric covered structure, and which therefore comes under this classification. It is really the practical solution of some of the problems outlined earlier in this paper and as such it is by no means the final answer.

This system consists essentially of a single spar (placed at approx. 0.3 of the chord) and two tension helices together forming a system of pyramid bracing which resists torsion in each of the two senses.

The apices of the pyramids are kept apart by compression members parallel to the wing chord, which can either be separate struts or incorporate with the wing ribs themselves.

Drag and anti-drag loads are catered for by this pyramid bracing in conjunction with tension members joining the apices along the span. The front member can very conveniently be the leading edge of the wing, and if con-

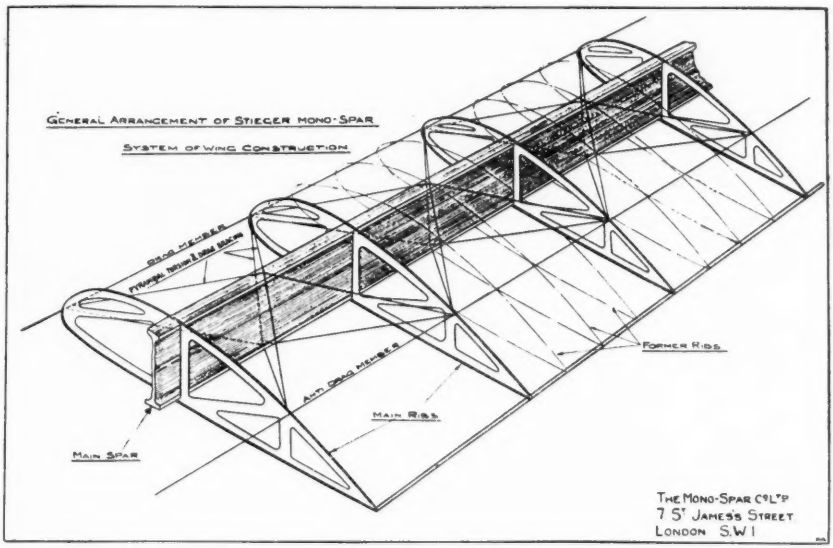

FIG. 17.
Monospar principle.

structed so that it can take compression as well as tension, the rear member can be dispensed with. A particularly desirable feature of the pyramid bracing is that once it is correctly installed it needs no subsequent attention as regards rigging. The tension members themselves are comparatively short; they are tie-rods and not wires, and consequently there is no question of vibration. They experience no shock loads since the centre of pressure on a wing cannot change position instantaneously. In the remote event of a tie-rod breaking, the torsion is released on to the spar over that particular pyramid, and it has to be taken mainly by the resistance of the spar booms to lateral bending. This can be provided against in the spar design without extra expenditure of weight. By arranging that the compression members between the apices of the pyramids on each side of the wing spar are made to stabilise the spar booms, the case of a cut wire only releases lateral bending loads over *half* the pyramid bay length.

In addition the drag and anti-drag members and also the secondary rib structure come into action and take quite a proportion of the torsion loads.

A Monospar machine has been successfully flown and all normal manœuvres carried out with alternative tie-rods completely removed.

The design calculations for such a system are comparatively simple, since the structure can be considered non-redundant, and the torsional deflection can

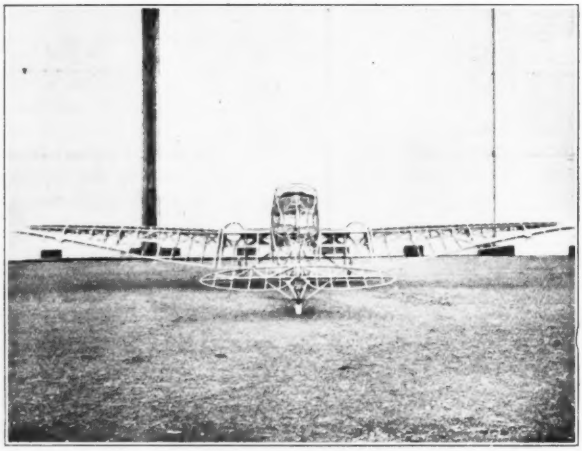

FIG. 18.
SSI. photograph.

FIG. 18A.
SSI. photograph.

be easily determined if the very small contributions of the wing spar itself and of the drag members are neglected. This deflection is halved if initial tension is put into the pyramid bracing. Initial tension obviously does not adversely affect the system at the instant the design torsion is attained, and the torsional deflection can easily be calculated within a few per cent., which is, of course, very important.

Generally speaking, the C.P.F. case indicates the design of the wing spar, the C.P.B. case figures together with the end loads in the spar booms due to the wing torsion being less almost invariably. The terminal dive torsion and drag loads cater for the pyramid bracing. Over the tip portion of the wing, the terminal dive case also claims priority over the torsion due to operation of the aileron.

Fig. 19 shows the skeleton of a Monospar wing built for a Fokker F. VII.A. It should be noted that in the centre a special adaptor bracket has been fitted to pick up the existing fuselage fittings.

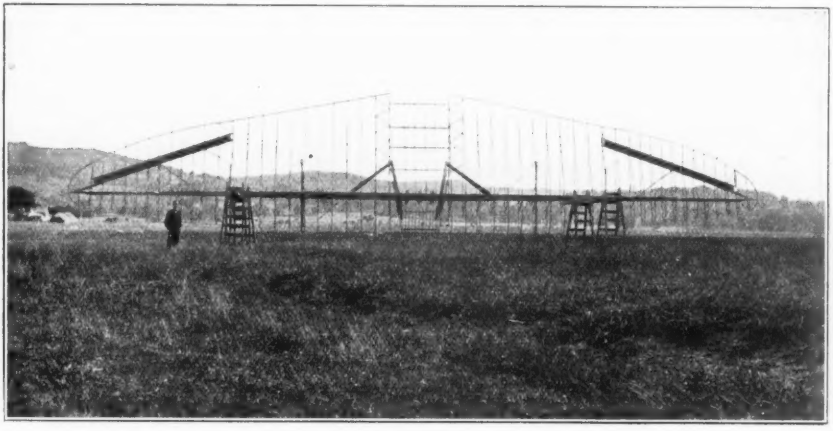

FIG. 19.
Fokker F. VII A. photograph.

Incidentally, the two half strut pyramids inboard of the wing engines weigh about half of the whole torsion bracing (see weight analysis), a substantial increase which shows the inefficiency of compression members as against tension members on a weight basis.

The wing tip is of the triangular construction outlined in Fig. 8. It is obvious that a certain amount of weight can be saved with this triangular type, as the auxiliary aileron spar, which has to be there anyhow, provides for torsional stiffness at the same time. The wing is fitted with two tanks strapped on either side of the spar, and there are two wing engine mountings. Incidentally, the two engine mountings fixed on to the single spar are some 28 per cent. lighter than the original ones fixed on to two spars.

Comparing this type of pyramid bracing with the normal double drag bracing of a corresponding two-spar wing, one finds the difference in weight is within a few per cent., *i.e.*, the single spar torsion and drag bracing is, in actual practice, no heavier than normal double drag bracing. This is due to having one compression tube as against a heavy compression rib, and this single tube is stabilised in the middle.

The wing section used in this wing has a C.P. travel of approximately 11 per cent. over the flying range. The reason for choosing it was entirely to get a better minimum drag combined with maximum lift.

As a matter of interest, we have worked out the additional amount of weight necessary to cater for the original wing section with its bigger C.P. travel. The difference is less than 20lbs.

All Monospar wings so far constructed have been designed just for the necessary torsional strength, and tests have shown that this gives sufficient rigidity to rule out flutter or aileron reversal. The stiffness can easily be increased by the use of heavier tension members. Doubling the stiffness means adding 25lbs. to a wing of the above size. Naturally the fabric covering contributes a certain amount of torsional stiffness to all wings. The actual amount varies very much according to the type of wing construction, and to the condition of the fabric. To prove that the Monospar system does not rely on the fabric we have carried out a number of terminal dives with the fabric completely slackened with dope remover. No signs of flutter or loss of aileron control were apparent. The diving speed was nearly three times the theoretical reversal speed calculated on a standard two-spar semi-rigid wing assumption, which gives a very good idea of the effectiveness of this type of triangular tip construction and the Monospar construction as a whole.

With regard to flutter, I only want to say that a single spar at about .28-.30 of the chord, a correspondingly low moment of inertia for the wing, and a principal inertia axis approximately coinciding with the flexural axis, is as near the ideal as possible and the full scale tests have confirmed this.

It is not possible to set a fixed degree of torsional stiffness, although in Germany, for instance, I believe there is an airworthiness regulation that the maximum torsional deflection in the terminal dive case must not exceed $3\frac{1}{2}^{\circ}$.

It is quite definite that a single spar fabric-covered wing can be much more flexible without any danger from flutter than, for instance, a multi-spar wing with rigid covering.

Another important point to be borne in mind is that a wing must not only be torsionally stiff under static load, but also under the conditions encountered in the air; in other words, the torsion-resisting members must be independent of the normal bending loads and wing deflection under load.

Flexibility of Wings

As already indicated a certain stiffness is necessary both in torsion and in bending to prevent wing flutter and aileron reversal, but personally I feel very strongly that these two phenomena should be met as far as possible by suitable aerodynamic and structural lay-out and weight distribution. Furthermore, the bending stiffness of the wings should be kept as low as possible, because the degree of flexibility of the wings helps to absorb dangerous bumps. The result is that the flexible wing system will prove in practice much stronger and more reliable than an extremely stiff system. After all, who would drive an unsprung car with solid tyres at high speed over a bad road?

The Meaning of Weight-Saving to the Aircraft Operator

It is difficult to compare wing weights on a fair basis due to the variation of design conditions, load factors, wing loading, etc., and also due to the doubt as to the precise amount of centre structure which should be included. For aircraft varying in all-up weight from 8,000lbs. to 20,000lbs., a general figure for wing weight is 15-18 per cent. of the all-up weight. In the case of Monospar wing construction the figure is reduced to 10 per cent., *i.e.*, to be conservative, a reduction of about 6 per cent.

MONOSPAR WING FOR FOKKER F. VII.A. 3 M.
" All-up " Weight, 8,000lbs.
Wing Area, 630 sq. ft.

MEASURED WEIGHT ANALYSIS.

Item.	Item weight lbs.	Group weight lbs.	lbs./sq.ft.	Per cent. of net wing weight.
Primary Structure.				
Wing spar	297	316	0.501	40.52
Root attachment and wing engine mounting fittings	19			
Torsion bracing, pyramid tubes and fittings ...	51	78	0.124	10.00
Strut pyramids inboard of wing engines	27			
Auxiliary aileron spars and bracing members ...	—	20	0.032	2.56
Total Primary Structure...	—	414	0.657	53.08
Secondary Structure.				
Ribs	—	120	0.190	15.38
Stringers, nosing, leading and trailing edges ...	—	44	0.070	5.64
Fabric and dope to wing (less ailerons 569.5 sq. ft.)	—	116	0.184	14.88
Total Secondary Structure	—	280	0.444	35.90
Ailerons				
Skeleton ailerons	31	56	0.089	7.18
Fabric and dope (60.5 sq. ft.)	11			
Static balance wts. ...	14			
Controls and Miscellaneous.				
Aileron controls in wing...	20	30	0.048	3.84
Electrical equipment, wireless aerial masts, pitot tube, etc.	10			
Total net wing weight ...	—	780	1.238	100

The wing weight is 9.75 per cent. of the " all-up " weight.

Let us assume a commercial machine with a range duration of 4-5 hours and a cruising speed of not less than 100 m.p.h., then the pay load will probably be of the order of 20 per cent. of the all-up weight.

Now if we can save about 6 per cent. of the all-up weight on the wings, *i.e.*, reduce the wing structure from 16 to 10 per cent., this means we increase the pay load from 20 to 26 per cent., *i.e.*, by 30 per cent. In other words, we could build a machine 23 per cent. smaller in size, with engines of lower power, costing less in the first place and having lower running costs to do the same work.

The saving can alternatively be used to increase the range of a commercial machine by about 40 per cent., or to provide a really comfortable cabin for the passengers. To my mind the effect of an increase of some 30 per cent. in pay/load

on the progress of civil aviation cannot be over-estimated, because it should enable it to free itself from the unnatural state of partial dependence on a subsidy, and even make it a paying proposition. It is true, one might argue, that our present-day air liners are seldom completely full, and therefore the extra 30 per cent. would be seldom used, but the same percentage of pay/load actually carried applies to smaller aircraft. If we want more people to travel by air we have to put the right type of machine into service. To my mind the big advantage of air travel is speed. If we put a big air liner into service running once a day from one town to another in about $2\frac{1}{2}$ hours, and it takes the passenger in addition $\frac{3}{4}$ hour between aerodrome and centre of town (*i.e.*, a total of 4 hours), and then we compare it with a fast train service running day and night at a 3 or 4 hours interval, then the air service has not got a fair chance. There is only one way, *i.e.*, a fleet of smaller machines running at frequent intervals and, if necessary, duplication of the service at the time when the amount of traffic provides justification.

Returning to the question of wing weight, it does not mean that having achieved a weight of 9.8 per cent. of the all-up weight without going to a high landing speed or a bad aspect ratio, or a very thick and inefficient wing (*i.e.*, a monoplane wing weight lower than most if not any biplane wing of similar size) that we have reached the limit. I know, perhaps better than most people, how far the Monospar wing falls short of the ideal and how much more weight could be saved.

If I predict a wing weight of $7\frac{1}{2}$ per cent. of the all-up weight (*i.e.*, roughly half of that in present-day machines) you will not believe me, but do not worry, I shall not try to convince anybody yet.

May I extend my thanks to Mr. Crocombe and Mr. Redshaw for the help they have given me in writing up this paper. I hope very much that the subject matter will create differences of opinion, because arguments and criticisms and exchange of ideas help to make for progress more than anything else. Especially I hope that the biplane exponents will come forward in force and include their views in the discussion.

Discussion

Mr. McKinnon Wood (*Member of Council*), R.A.E.: It was with some diffidence that he personally contributed to the discussion, because structural questions were much involved in matters of detail. One might come to broad conclusions about structural strength without having taken into account the amount of weight involved in joining things together. He had never been a sufficiently close student of aeroplane structures to be able to express any confident opinion on the subject, but he could state his broad impressions. He was inclined to agree with the author that the fabric covered wing was the best proposition, and in not caring for plywood and aluminium covering and any attempt to make the skin act as part of the main structure. He also agreed with the author's remarks concerning the multi-spar wing. It seemed to him that if one had spars in a wing one might as well make their bending stiffness contribute as much as possible to resist twisting, and that led to putting the spars as far apart as possible; but one should not put them too far apart because their depth contracted as the wing depth contracted. So one came to the two-spar wing, he imagined, as preferable to the multi-spar. Mr. Stieger wanted to go to the single-spar wing. One felt that he was certainly right in laying emphasis upon the importance of having a wing which was torsionally stiff, by which he (Mr. Wood) meant a wing which was torsionally stiff when removed from the aircraft, and was not resisting twisting by the bending stiffness of spars. Mr. Farren, in his paper on "Monoplanes and Biplanes," had shown the marvellous extent to which torsional stiffness distributed the load as one would like it distributed between the two spars for wide variations of centre of pressure, and Mr. Stieger

had said that with the two-spar wing one spar was often doing most of the work. Mr. Wood suggested, however, that with a reasonable amount of torsional stiffness that was not really the case. It seemed to him to be still an open question whether some arrangement of two spars fairly close together or Mr. Stieger's single spar arrangement was the more economical proposition, as shown by the two sketches beneath.

FIG. 1.

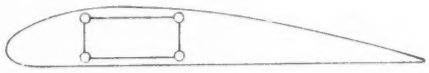

FIG. 2.

He felt that one would obtain the greatest torsional stiffness for a given weight of material added to give torsional stiffness, when one could get that material introduced, as shown in his Fig. 1, than if it were introduced in a diamond shape as in his Fig. 2, enclosing a smaller area. No doubt Mr. Stieger had studied that matter in great detail and probably could put forward some mathematical arguments on those lines, which would be very useful as an Appendix to the paper. Perhaps Mr. Stieger had felt that he must steer clear of mathematics and figures in writing the paper and must give only his general conclusions, but it would be interesting if he would deal with that particular point in rather more detail. Mr. Wood confessed that, after having heard the paper read, he remained still unconvinced.

In making a comparison between the twist-resisting power of a wing which was relying largely on the bending stiffness of the spars and one relying on torsional stiffness, one had to proceed very warily, because the variation of twist along the span would be very different in the two cases. The flexurally stiff wing would have a twist increasing much more rapidly towards the tip than would the other wing, and one must be very careful in defining one's basis of comparison.

A suggestion had been made in the paper—and to Mr. Wood it was just a suggestion, but possibly Mr. Stieger had some definite evidence about it—concerning what was referred to as " the trailing edge angle "; presumably Mr. Stieger meant the included angle of the wing section at the trailing edge. He had suggested that there would be an earlier and more sudden stall if that angle increased. Mr. Wood asked for further information on that matter, because he was not aware that, within wide limits, this made much difference.

Mr. DUNCANSON: Mr. Stieger's invention was one of the most important advances in aeronautical design put forward within recent years. He recalled that there was a tremendous amount of opposition and incredulity on the part of the whole of the aircraft industry when his proposals were put forward. He was very much to be congratulated upon having managed to prove his case, and to construct an actual machine and have it flown and demonstrated. He had made such an overwhelming case in favour of the cantilever wing that to re-open the biplane *versus* monoplane controversy was sheer waste of time, and it might be dismissed, with the reservation that for certain types one could not very well do anything else but use a biplane. Mr. Duncanson said he had never had any doubt about the success of the Monospar construction, as he had been working on the theory for a year or two before the advent of the Monospar, which had shown that there were vast possibilities in this form of construction. He had watched the process of construction both of the small twin-engined monoplane

and the Stieger wing for the Fokker with intense interest at the Gloster works, and confessed that at times he had had very grave doubts as to whether the torsional stiffness would be adequate. It had been proved conclusively by flight tests, however, that there was nothing to worry about on that score. The results were nothing short of marvellous. They showed that there must be an art as well as a science in the design of a successful cantilever wing, and it was a very significant fact that according to conventional British airworthiness requirements the torsional stiffness of Mr. Stieger's wing ought to have been many times greater than it was found to be when tested on the ground. This showed that there must be something radically wrong with the theories postulated by our mathematicians and those responsible for laying down the rules governing the design of cantilever wings in this country. He had the greatest admiration for the achievements of our research workers—and no one appreciated more than he the difficulties involved in the mathematical treatment of cantilever wings—but he believed the time had not yet come for them to lay down hard and fast rules and to give any criterion for the torsional rigidity required of a cantilever wing. He suggested that in the meantime it would be far more satisfactory for them to work on the same lines as the Germans, using their criterion of about $3\frac{1}{2}$ degrees on the terminal nose dive condition, because if they had to continue working to a rather absurd criterion it would handicap the progress of cantilever wing design and they would not have a chance of competing with the foreigner.

The description given by Mr. Stieger had commenced with the tubular spar. This happened to be the form on which his (Mr. Duncanson's) mathematical thesis was based, and it was rather interesting that the theory had come first and the practical construction second; as a rule the position was reversed—usually the practical engineer made a thing and the scientist then told him how he had done it.

In answer to the criticism that the drag bending deflection with his spar would be large, he said that on the first full-scale test a spar was subjected to the fully factored nose dive bending and torsional loads, and the deflections were so minute that special apparatus had to be used to measure them. In this connection he acknowledged the help given by Mr. Gerrard, of M.T. department, R.A.E., who had developed a very ingenious method of measuring these small deflections; he also acknowledged the courtesy of the Monospar Company in supplying him with data of the shear, bending and torsional curves.

As regards the torsional stiffness in the tubular spar, the tests had confirmed his prediction that the total twist at the wing tip under the full effect of nose dive torque would be less than 2 degrees. This would exceed the German airworthiness requirements by about 100 per cent. With regard to the contention that it would be inefficient as a beam, he said that the spar was not nearly so heavy as Mr. Stieger thought it was. In any case, the primary consideration in the cantilever wing spar must be torsional stiffness, and beam efficiency came next. There were very sound scientific reasons why the tubular spar should be lighter than any other for the cantilever, but there was not time to explain them. He heartily endorsed Mr. Stieger's opinion regarding bending stiffness, and considered that, within reason, a large bending deflection was advantageous. The same applied to the rib as to the spar.

Finally, he emphasised that the aeronautical world as a whole owed a great debt of gratitude to Mr. Stieger and his associates for a very brilliant piece of pioneer work.

Mr. HOLLIS-WILLIAMS (Messrs. Fairey Aviation Co.): All the pet theories of designers had been shot to pieces by Mr. Stieger. They had cherished the idea that they would never be able to make a cantilever monoplane structure lighter than the wire-braced biplane structure, and so long as their monoplane structures were not very much heavier than the equivalent biplane structures they had thought they had done very well. He belonged to the firm of which

Mr. Fairey (the President of the Society) was the distinguished head. Mr. Stieger had said that the fabric covered monoplane wing ought to be built at 1¼lbs. per sq. ft., and probably Mr. Fairey was wondering why his monoplane wings were not built to 1¼lbs. per sq. ft. People in his (Mr. Williams') position were therefore placed on the defensive; and he proposed to attempt to explain just how much the Monospar principle and how much Mr. Stieger's design were separately responsible for the low weights achieved.

The Monospar had always been a mystery to him. He had heard some extraordinary statements, and only as the result of obtaining figures had he been able to see daylight. However, he did not wish to detract in any way from Mr. Stieger's magnificent achievement; after all, the proof of the pudding was in the eating. The Monospar wing, to be demonstrated properly, must justify itself by a light structure and everything depended on the designer choosing his conditions very carefully, particularly as regards low wing moment. The weight of a first experimental machine was no criterion of the weight of production machines. A big firm had a millstone of experience round its neck. It had a big staff of draughtsmen, and perhaps every one of them was used to doing some particular fitting. Probably each of them remembered that in one case he had made a fitting lighter, but trouble had occurred as a result, and he had had to increase the weight again.

He had noted that Mr. Stieger had made his secondary structure at just under ½lb. per sq. ft. The figures relating to the Fairey Company's biplanes and monoplanes, however, showed that they had never achieved very much less weight than 1lb. per sq. ft. on the secondary structures. Thus, there was ½lb. extra, which was the millstone of their experience. They could not make it less; they had tried, but trouble had occurred. Again, Mr. Stieger had managed to make his primary structure at just over 0.6lb. per sq. ft. The weight of the Fairey Company's primary structures was just under 1lb. per sq. ft., and in the case of braced biplanes, but in the case of cantilever monoplanes, of which they had had experience of two large ones, it was just over 1lb. per sq. ft. Thus, there was nearly another ½lb. lost there. He had tried to separate out how much was due to the Monospar principle and how much was due to Mr. Stieger's daring design. The Monospar principle, he concluded, was responsible for the difference between 0.65lbs. per sq. ft. and, say, 1.1lbs. per sq. ft. The former figure had been achieved by Mr. Stieger, and, working with the same material, duralumin, of which he had had no experience, Mr. Williams believed that he could possibly achieve 1.1lbs. per sq. ft. So that the conclusion was that the Monospar was worth to anybody nearly ½lb. per sq. ft. The next logical consideration was that if it were costing ½lb. per sq. ft. to have more than one spar, were there other advantages in having multi-spars? He must say that one had to look a long way to find them, and in commercial machines he doubted that there were any; in military machines which might have to withstand gunfire some redundancy even at the expense of weight was probably worth while. It appeared that there was ½lb. per sq. ft. to be gained by going to the single spar, but there would be a considerable amount of prejudice to overcome before it became general.

The average pilot would say that he was all for the multi-spar, because he had the feeling that that wing was stronger, which of course is probably true at C.P. positions between the limiting positions.

However, whether by Monospar principle or by daring secondary structure design, Mr. Stieger had accomplished a very remarkable structure weight for which he deserved every credit.

Dr. LACHMANN (Messrs Handley Page): He congratulated Mr. Stieger on his boldness, both in regard to his ingenious invention and also in pleading for monoplanes in a country which was so essentially biplane-minded. The only point on which one could differ from him was as to how the torsion could best be taken up in the structure. Reference had been made by the lecturer to the

B.F.W. construction, which Dr. Lachmann believed was one of the oldest and best tried out of single spar constructions. It had one strong spar and a skin covered nose which took up the torsion.

Mr. Stieger had referred to some tests published in the D.V.L. Year Book of 1931, but the way in which he had reported these test results might have created the impression that the method of taking up torsion in a skin-covered nose was unreliable and uneconomical. Perhaps it would be well to point out that the tests referred to were made solely for the purpose of establishing experimentally a certain theory, the theory of how to calculate the torsional stiffness in a skin-covered wing structure. A good deal of theoretical and experimental research work had been done recently on these lines and fortunately the calculation for tubular structures was very simple. It was based on the well-known analogy where the torsional problem is reduced to one of hydrodynamics with the lines of equal shear replaced by the streamlines of the flow of constant vorticity between the boundaries of the wall. By application of Stokes law Bredt had found a simple formula for the torsional deflection and stresses and which had been further developed by Hertel in Germany to cover the case of a tubular structure with a diaphragm. In checking up the formula it was found that the torsional deflections calculated by the formula were in close agreement with the prediction for small loads; as the loads increased a discrepancy occurred which could be expressed by coefficients. The object of these tests was to supply designers with a reliable basis for strength calculations, and it would therefore not be fair to deduce from the discrepancy between theory and test results the inferiority of such structures where torsion was taken up by curved panels.

Wings designed and built on this method were not very inferior in regard to weight to Mr. Stieger's design, a machine of 2,000lbs. total weight having a wing weight of only 1.35lbs. per sq. ft. and a larger machine of 6,600lbs. having a wing weight of 1.45lbs. per sq. ft. By analysing the various components of the structure weight a percentage of the weight of the skin used in such a structure was of the order of 13 per cent., including the stiffeners, and comparing that with the figure which Mr. Stieger had given for the weight of torsional bracing employed in his structure, it meant an addition to the total weight of the wing of 3 to 4 per cent. Apart from this slight inferiority in regard to weight, there was, however, the advantage of a greater redundancy of the structure.

Discussing torsion generally, Dr. Lachmann said that if devices which increased the lift were applied, it was possible to use a wing section having a very small moment in the nose dive condition. The only torsion which had then to be considered seriously was that due to the ailerons, but this moment was only a percentage of the nose dive moment for ordinary wing sections.

With regard to Mr. Stieger's suggestion to use a reversed differential aileron control on wings with a reflex trailing edge, he asked what happened to the yawing moment produced by the down-going aileron. He had always thought that the main advantage of differential control was the fact that the yawing moment on the down-going aileron was reduced, but with reversed differential control it was increased, although an improvement might be found in the balance.

He had been very interested in the construction of the wing root which Mr. Stieger had shown on one of the slides, and he had had an opportunity recently of seeing a small low-wing monoplane where a different scheme had been fitted for the same purpose, viz., curved fillets between wing root and fuselage. The object was to avoid any divergence of the flow towards the trailing edge and he was told that where the machine had previously shown very bad buffeting characteristics it had been completely cured by this type of fairing.

Mr. POLLARD (Bristol Aeroplane Co.): Commenting upon Mr. Stieger's suggestion concerning the Bristol experimental wing, that it must be practically impossible to calculate the accurate load distribution on the spars under different flying conditions without an extensive series of tests, he asked why one should

calculate the load distribution on the different spars—provided there was one case which covered them all and provided the loads could be accurately calculated in that one case.

If a wing having a centre of pressure nearly constant was considered then with the pressure distribution diagram, the appropriate loads on each spar and the deflection of each spar was readily obtained, it was an easy matter to dispose the spars and the material in each spar so that the deflection is greater for this case than for any other; it was, in fact, quite possible to arrange for the rearmost spar deflection to be less for the worst C.P.B. case than for the case of C.P.F., having regard to the load factor for that case, consequently the loads in the rear spar were covered by the C.P.F. case. The multi-spar wing should only be considered at this stage of development in connection with the very large aeroplane for which no inverted flying condition was required, and as regards the T.N.D. case it was an easy matter to show that the spars subjected to reverse load were amply strong for that purpose providing a reasonable wing section was chosen; in brief, he assured Mr. Stieger that they had ascertained that the calculations which were made were good, simple, and fully adequate for their purposes.

Again, it had been suggested by Mr. Stieger that the multi-spar wing should be designed on the assumption that all the stresses were constant in all the members. That, however, was quite incorrect. What was aimed at in multi-spar design was not uniformity of stress in all the members, but uniformity in the individual units composing a single spar. The deflection of the spars should, at the same time, be the same under their separate and different loads; with these conditions and normal flying there would be no twist in the wing. This can only be attained by having different stresses in the spars; these spar stresses were also influenced, of course, by the spar depths. In connection with that Mr. Stieger had exhibited a slide showing a difference in depth of spar, in the multi-spar wing, of 3/1. That was grossly exaggerated. The variation need not be more than 1/0.85.

Adverse reference was also made in the paper to the small moment of inertia of individual booms in the multi-spar wing, and this touched the crux of the whole matter; it was not right to mention this feature by itself, other factors must be considered. The facts are simple. A rigid skin was chosen, firstly because by its use great torsional stiffness was obtained; secondly, a robust structure of great permanence could be assured, but a thin uncorrugated metal skin could only be used if it was reinforced at frequent intervals—and in the Bristol construction the reinforcements used were the spar booms, these being made from steel strip. The effect of the skin on the booms was to increase their resistance to buckling very considerably; in fact, the possibility of buckling was completely eliminated in the plane of the skin, while at right angles, *i.e.*, perpendicular to the skin, the radius of gyration was, in effect, increased by anything up to 50 per cent. of that of the booms themselves, and for that reason the stabilisers (if by that the lecturer meant the shear members) were not placed close together, but at distances at least as far apart as in the case of similar members shown in the pictures of his Monospar, consequently the Stieger construction did not, to say the least, show any advantage in this respect.

The metal strip construction of the booms of multi-spar wings makes it particularly easy to vary sectional areas of booms; this fact, combined with the stiffening effect of the skin referred to, very largely helps to compensate in weight for the greater density of the metal covering compared with the density of fabric. One could use stainless steel, in fact, "which does not burn like paper in the event of a crash." All this meant many members, he agreed, but he was not at all sure that a redundant structure was altogether a bad thing, particularly in warfare; if it were possible to avoid a catastrophe when primary members,

such as spar booms, for instance, failed through fatigue or for some other reason, then redundancy was a point worth consideration.

With regard to flutter, he suggested that Mr. Stieger was rather dogmatic in stating that the danger from flutter was much less with a Monospar wing than a multi-spar wing with rigid covering. Mr. Pollard asked what evidence there was for that statement. In the Bristol multi-spar wing the maximum twist was less than $\frac{3}{4}$ degree over a 40-foot length, while the flexural axis was just ahead of the centre of pressure.

As to reversal of control, Mr. Stieger had stated that comparative calculations had been made of the two-spar wing and the Monospar, and that the Monospar could dive at three times the theoretical reversal speed calculated on a standard two-spar semi-rigid wing assumption. He (Mr. Pollard) had looked into the records, and the slowest reversal control he could find was 100 m.p.h. It was interesting to know that a Monospar wing could be safely dived at 300 m.p.h.

There was some disadvantage in the initial tightening of the tension wires, and it was not easy to see that the torsional twist was reduced by half irrespective of the amount of that tensioning. That feature was of considerable importance from the point of view of the private owner. Even in a biplane there was trouble in keeping the wires taut, but it must be done, and it seemed to him that the private owner would not wish to be bothered with keeping wires up to a special degree of tautness, and in that respect a rigid riveted wing from which wires are entirely absent, made from stainless steel and in consequence requiring no attention whatever, will make the stronger appeal all round. Riveting had been mentioned as being troublesome. He considered, however, that riveting always looked far more expensive than it really was, provided the rivets were only inserted in readily-accessible places. Means of either eliminating riveting or quickening up production were always being evolved; in brief, riveting was all right when one knew where and how to do it. With the multi-spar wing, spot welding on stainless steel seemed to be a very promising method of manufacture.

Finally, Mr. Pollard expressed the view that the Monospar wing was a very fine invention, particularly for small machines. Mr. Stieger was to be congratulated on his departure from standard practices, and upon the very able manner in which he had presented his case.

Mr. METTAM (Westland Aircraft Company): It had been suggested that designers would not admit that they had been beaten, but Mr. Williams had admitted it, and he himself was also prepared to admit it. He called attention to one type of aircraft which had not been referred to in the paper, *i.e.*, the strut-braced or wire-braced monoplane; it might be that the author had been thinking particularly in terms of larger aircraft, where that construction might be difficult to achieve. Neither he (Mr. Mettam) nor his firm were monoplane maniacs, but they did contend that they could build braced monoplanes which were as free from flutter troubles as were biplanes, having good aerodynamic characteristics and wing weights which were at least as good as those of the average biplane. With regard to rib weights, the lecturer had stated that a certain biplane rib was of the same weight for a two-spar machine as the rib for his Monospar aircraft. Mr. Mettam did not think, however, that that necessarily proved that the ribs for the Monospar aircraft would always be of less or equal weight; did it not rather prove that the lecturer, giving the same trouble to the rib for the biplane aircraft, would have got a still lighter rib?

He was very pleased to know that the lecturer had referred to a tail as an unnecessary organ for controlling an inefficient wing surface. What the lecturer really wanted was a Pterodactyl, although he had not said so. In that type of aircraft one had what Mr. Stieger wished to have, the wash out towards the wing tip and the taper towards the wing tip, and he confirmed the statement

that a wash out led to very little loss in maximum lift. With regard to the wash out at the centre section, as the lecturer had proposed, he believed that the loss of lift was really less serious than the increase of induced drag due to the downward kink in the lift curve at the centre section.

In asking what was the greatest speed range of any Monospar aircraft, Mr. Mettam said that one need not necessarily know the greatest speed at which it had been dived, but the greatest speed range from stalling to the speed at which the machine was flown without experiencing any reversal of control. He also asked what was the C.P. forward factor to which the Fokker Monospar wing was designed. With regard to the removal of wires, he asked whether the wires which were removed had to be chosen specially, or whether any wires could be removed at the will of a malevolent but intelligent engineer who happened to have a grudge against the test pilot!

Mr. SPENCER (R.A.E.): The author had mentioned some recent full-scale experiments which had shown that there was heaviness in the lateral control at high speed, and had attributed this to the reflex trailing edge of the aerofoil section concerned and to the differential movement of the aileron. He asked what measurements were made during these tests to separate out the effects due to these causes from those due to wing twist, the two effects being indistinguishable to the pilot.

Another statement to which Mr. Spencer referred was that aircraft constructors who had tried to make the skin take bending loads besides torsion had had to give it up, and that all of them now used it only to resist torsion and drag loads. In the Junkers design, said Mr. Spencer, the skin did not contribute directly to the bending stiffness, but inasmuch as it stabilised the tubes which were taking the bending stresses it did contribute indirectly very materially. In tests carried out at the R.A.E. some years ago on a Junkers wing it was found that the stabilising effect of the skin enabled the top compression tubes to take approximately double the stress they would otherwise have been able to develop.

Referring to the author's statement that if fabric were good enough for our fastest fighters it was good enough for commercial machines, Mr. Spencer said it was not quite clear what was meant by "good enough." Considered purely as a covering there was no doubt that fabric was good enough, both for Service and for civil aircraft; but was it implied that any reliance should be placed on the fabric to contribute to stiffness or strength? Considerable information had been obtained recently showing that fabric was a very unreliable material to count upon, and although in certain circumstances, particularly when new, it might contribute quite materially to the stiffness, in conditions which might arise when it was old its contribution might be practically nil. With regard to the author's statement that "all Monospar wings so far constructed have been designed just for the necessary torsional strength, and tests have shown that this gives sufficient rigidity to rule out flutter or aileron reversal," Mr. Spencer asked whether the machines referred to had been fitted with mass-balanced ailerons. If so, why did he attribute freedom from flutter to adequate torsional stiffness rather than to the mass balance? Later the author had stated that doubling the stiffness meant adding 25 lbs. to a wing of the above size. How did he define the stiffness? The method proposed for increasing the stiffness was to increase the size of the tension bracing members. That, suggested Mr. Spencer, would make no difference to the twisting which took place in the outboard regions of the wing. With regard to the statement that, in order to prove that the Monospar system did not rely on the fabric, a number of terminal dives had been carried out with the fabric completely slackened with dope remover, Mr. Spencer asked for some figures showing the measured stiffness of the wing: (1) When the fabric was doped, *i.e.*, in its normal condition; (2) when it had been doped and treated with dope remover; and (3) either when covered with undoped fabric or when completely uncovered. Such figures would give some

measure of the success of the dope remover in reproducing the worst conditions in the fabric that were likely to be encountered during the subsequent service of the aircraft.

Flight-Lieut. H. M. SCHOFIELD: With reference to diving, machines had been dived under varying conditions. With the fabric slack, a recorded top speed of 178 m.p.h. had been reached—and he supposed the corrected speed would be something near 200 m.p.h. There was no trouble during diving up to that speed, no tendency to reversal and no deflections noticed. With regard to the removal of torsional bracing tie rods, he said these were taken out indiscriminately, and in one case certain of them were taken out as indicated by another firm which had been asked to suggest which should be removed, but he had experienced no serious troubles as a result. With regard to aileron loads, he had noticed that towards normal top speeds in small machines—round about 130 m.p.h.—there had been a tendency towards heaviness in control. It was usual to work on the lines that a balance wire was a balance wire, and that the load be taken on the opposing wires. He believed they had still to prove that the author was right—and he personally was of opinion that he was right—that normal differential conditions were reversed at the trailing edge with the reflex section of wing; that is to say, that with a reflex wing section differential control should be applied in the opposite direction to orthodox design.

Mr. M. L. BRAMSON: He was associated, in a non-technical capacity, with Mr. Stieger for part of the time during which he was carrying out his experiments. He assured the meeting that although Mr. Stieger had been referred to as daring and bold, he had in fact been most painstaking, prudent and careful, and it was only as the result of such prudence and care that he had, for example, arrived at the remarkable result that his secondary structure weighed only about half what other people considered to be the lower limit. At the risk of depriving Mr. Stieger of some of his ammunition—which no doubt would be directed towards Mr. Pollard—Mr. Bramson said it had always been his impression that a measure of the efficiency of an engineering structure was, apart from details, uniformity of stress throughout the structure; therefore, Mr. Stieger's assumption that the stress was to be uniform in the various spars of the multi-spar wing was a reasonable one, and the contrary case would simply mean that the spars were heavier than they needed to be for the loads they had to carry. It was quite clear that one could make the deflection uniform from spar to spar, but only at the cost of increasing the weight of some of the spars, and that was Mr. Stieger's point. For one designer to have invented a system which was a radical departure from the practice usually followed, to have carried it out in every detail personally in the two cases in which it had been applied, with complete success, and without a single instance of a departure from predicted values, whether as to weight or strength, beyond 2 or 3 per cent., and having regard to the fact that where there had been such departures it had been shown that his estimates had been conservative, was nothing short of a brilliant achievement, of which Mr. Bramson did not know a parallel.

Mr. A. F. SCROGGS (*communicated*): He was very interested in the author's arguments in favour of the monoplane, a type which he had favoured for some years—particularly the low-wing type.

He was glad to see the importance Mr. Stieger attaches to torsional stiffness of wings; a matter which he thought is sometimes insufficiently considered.

As a result of a somewhat varied experience, he had come to the conclusion that wing flexure is sometimes the cause of ineffective control when the blame is laid on the controls themselves. Certain aeroplanes having outstanding good aileron control appear to have exceptionally stiff wing structure—and this is not confined to biplanes.

He thoroughly agreed with Mr. Stieger as to the thinning down of the wing at the root to avoid tail buffeting.

As the Monospar type seems to make this easy, he was very interested in the latest Monospar machine and would welcome an opportunity to test it.

Mr. W. S. FARREN, F.R.Ae.S. (*contributed*): He regretted that he was not able to be present at Mr. Stieger's lecture, the more so as the proofs circulated did not include the diagrams to which he refers. He mentioned his own paper on an allied subject in terms which he felt somewhat distorted the conclusions to which he came. He would remind him that he worked on a basis of a fixed and fairly low landing speed, in itself unfavourable to the monoplane. Mr. Stieger rejects landing speed as a criterion, attaching to it the term " theoretical," whose precise meaning in this connection escapes one. He did not think they are yet in a position to regard the minimum speed at which a commercial aeroplane can lift its own weight, as irrelevant to its merits. Further, he assumed the same standard of " take-off " throughout and left the different characteristics of the schemes considered to appear as differences in top speed and paying load, which is not very different from the basis which Mr. Stieger favours. Moreover, he emphasised that the disparity (as he estimated it) between the types became less with a rise either of the landing speed permitted or the cruising speed demanded. Finally, he explicitly considered only those qualities which he regarded as measurable with fair certainty in terms of one another, leaving to others the task of bringing into the final account such considerations as cost, convenience, etc.

In the three years which have elapsed since that paper was written, a good deal has happened which would affect the conclusions of a similar analysis made to-day. In the first place it has become clear, as the result of experiments made both here and in the U.S.A. that the low resistance of the (multi-engine) internally-braced monoplane can be reduced still further by proper arrangement of the engine nacelles. Secondly, they have learnt a great deal about the properties of aerofoils generally, and of those suitable for such wings in particular. This is the outcome mainly of research in the variable density wind tunnel of the N.A.C.A., and it is now clear that a high maximum lift is not necessarily associated with a high moment coefficient. Thirdly, the terminal velocity condition of structural design for commercial aeroplanes of this class has been replaced by a more rational and less onerous condition. All these react to the advantage of the monoplane, especially when a high performance is required.

From the structural point of view (apart form the subject of Mr. Stieger's paper) there has not been so marked a change. The " stressed skin " is still regarded in most quarters as the most satisfactory means of attaining the necessary torsional stiffness. It has the demerits which Mr. Stieger mentions, but three years' further experience cannot be said to have tarnished its record of practical success. They are still unable to calculate the torsional stiffness of a structure of this type with any real certainty, and he entirely agreed with Mr. Stieger on the disadvantage which is inherent in such a state of affairs. It is to some extent mitigated by the difficulty, to which Mr. Stieger refers, of deciding on the degree of torsional stiffness necessary in any particular case.

It is evident that if there was, as was, he thought, widely agreed, a margin in favour of the biplane (for the purpose in question) three years ago, it has now become less, and may have disappeared. In an engineering problem of this nature, when the calculable characteristics of alternative schemes differ by amounts which hardly exceed the probable error involved, the wise designer turns his attention to other considerations—less easy to estimate quantitatively, but not less important.

Mr. Stieger's paper, as he read it, does not deal with the relative merits of various general schemes of wing construction for any specific range of types or sizes of machines. It deals with the design of internally-braced monoplanes. If a reasonable proportion, only, of what he claims can be realised, and if

experience with aeroplanes to his design proves that it stands up to the many demands on a wing structure which find no mention in the airworthiness requirements of this or any other country, his system is unlikely to be neglected.

Air Commodore J. A. CHAMIER (*communicated*): He did not want his remarks to be construed as criticism of the Monospar wing; Mr. Stieger knows that he is to a great extent a believer in the single-spar principle, but he thought they must be careful to have a proper perspective in which to view the great things which Mr. Stieger has done.

He felt that he has selected the type in some ways favourable to himself. The wings carry distributed loads. The section has a favourable C.P. shift, and by somewhat arbitrary assumptions as to the degree of torsional and bending rigidity necessary he has produced a cantilever wing to commercial factors of a weight per square foot of 1.24lbs. His admiration of this feat is not lessened by his inability to see how it has been done. In his particular Fokker he shows a saving over a " normal " wing of 6 per cent. in 16 per cent. on all-up weight. There is no reason to suppose that the Monospar structure *per se* effects a saving in secondary structure, which averages about half the total weight in an ordinary wing. The saving of 6 per cent. must, therefore, come off 8 per cent. of the all-up weight; a striking result. If he ever cuts off the additional 2½ per cent. which he promises us there should be no primary structure left.

Looked at from another angle, his wing has a total weight of 780 lbs., whereas a " normal " wing at 2 lbs. per sq. ft. should weigh about 1,260 lbs. His secondary structure, with miscellaneous equipment and covering, weighs 366 lbs., and there is no reason why it should weigh more on the " normal " pattern. They saw from this that the primary structure which he takes as " normal " must weigh about 894 lbs., and he reduces this to 414 lbs.!

They must assume that he has cheated a bit in his secondary structure and that a similar method is open to designers of more normal types.

Finally, he did not think that they should mix up the Monospar with the monoplane. The biplane folk can certainly produce a biplane to his conditions to the same weight, and so what Mr. Stieger really wants to say to the operator is this: " If you use a Monospar construction on a selected type you will save 6 per cent. of the total weight you would have had if you used a monoplane at 2 lbs. per sq. ft. A biplane or a wire braced thin-wing monoplane will do you just as well until I can show you how to build those types at a still further saving of weight."

Mr. B. W. TOWNSHEND, A.F.R.Ae.S. (*communicated*): There is one aspect of the question which has an important bearing on the future success of the Monospar wing, which did not receive the attention it deserved in the discussion which followed his paper, namely, that of maintenance.

In rigging and trueing-up a more conventional type of wing structure, the average rigger is able to appreciate the precise effect of adjustment to any given member. In the Monospar wing, however, where the functions of many of the members are not so apparent, it seems likely that this may prove to be a source of trouble in service.

The conclusions to be drawn from experience on wings so far constructed are extremely encouraging, but, as is the case with all experimental machines, there can be little doubt that maintenance has been in the hands of men who really know their work. What will happen when this type of construction comes into more general use, and repairs and maintenance often have to be effected by semi-skilled or unskilled labour, is still a matter for conjecture.

One other point on which information would be of interest relates to Mr. Stieger's experience with fabric covering on wing sections which are reflexed towards the trailing edge. One objection to the use of sections with any appreciable amount of reflex, when a fabric covering is used, has been that the tendency of the fabric to convexity over the reflex portion, combined with the

usual concavity between ribs over the remainder of the section, has given rise to such deformation of the true aerofoil section that the aerodynamical characteristics may be seriously different from those obtained on a wind-tunnel model having a true section over the whole span.

Mr. B. S. SHENSTONE, A.F.R.Ae.S. (*contributed*): Mr. Stieger is certainly to be congratulated for a very fine achievement in light wing construction. It is, however, not only his structural method which is worthy of mention, but also his aerodynamic method. He has shown the value of rational and careful structure and the advantage of using a well-tapered wing having a section with low C.P. travel. In the case of the Fokker F-VII wing, the increase in taper to almost twice the original value which has been done in the design of the Monospar wing, would (assuming same mean spar depth) result in a saving of around 85lbs. in the spar weight, which, added to the 20lbs. mentioned in the lecture as allowance for change of section, would make a saving of over 100lbs. due to aerodynamic changes alone. This is a point well worth regard, especially as the size of the aircraft increases.

As Dr. Lachmann has said, the elastic bowing of flat plate (forming tension diagonal fields) is not a sign of failure, but is just what must occur in such an initially unstable member when a more stable condition is attained. Metal aircraft construction has been defined as one using thin skins which wrinkle under load, as opposed to ship construction in which members are stable under shear. However, the point in connection with the formation of bowing in the outer skin is that the waved surface has more drag than the smooth one. But fabric stretched over ribs also presents a waved surface to the wind, and so the objection made to the thin metal skin is just as applicable to the present Monospar wings.

He agreed with Mr. Stieger that it is desirable to have a slight washout near the wing root in a low-wing monoplane, but found difficulty in believing that a thinning down of the root section is a cure for buffeting. As is well known, at high values of k_L when the velocity over the wing is considerably higher than that under the wing, the airstream above the wing is deflected toward the fuselage axis. In order to guide the air to the rear with the minimum of eddy formation, a very carefully designed filleting must be applied so that no abrupt changes of direction of the cross-flowing air are made. This has been carried out, for example, on a Junkers " Junior " to a rather exaggerated extent, but with very successful results, the buffeting being cured. On the other hand, if the section is thinned as suggested in the lecture, surely the air flow across the wing would have an even greater tendency to be deflected against the fuselage (due to the sharp slope of the wing) thereby creating a disturbance and causing buffeting, or at least breakdown of flow near the fuselage. One achieves a smaller trailing edge angle, but one may have achieved it dearly. In the case of the " Junior " the small trailing edge angle was cheaply obtained.

It may be of interest to note that in the newest German airworthiness regulations the formerly allowable $3\frac{1}{2}$ degrees torsional deflection in the nose dive has been discarded, and replaced by the following: " It is to be proved that wing oscillations intensified by the airstream cannot occur below the speed:—

$$v_k\ (m/\text{sec}) = 1.3\sqrt{(2\ .\ q_e/\rho)}.\text{"}$$

$q_e\ (kg/m^2)$ is the dynamic pressure corresponding to the nose dive case, and must be at least 2.25 q_h, where q_h is the dynamic pressure corresponding to maximum horizontal speed $\rho = 0.12\ kg^2/m^4$.

Mr. R. L. CARTER (*communicated*): Under the sub-heading Nos. 5, 6 and 7, Mr. Stieger says " the Ford wing relies upon the metal covering for torsional stiffness." It is presumed that this is a personal opinion.

The Ford wing in skeleton form is adequately strong enough to take any flight loads and, in fact, is a complete structure in itself and no allowances are

made whatsoever for any additional strength which may be put on by the wing coverings. The U.S.A. Department of Commerce have particularly notified the Ford Company to the effect that they do not consider the wing coverings as part of the structure and no allowance is being made for the wing covering in their strength checking.

The use of corrugated coverings for taking certain stresses is covered by a patent held by Messrs. Junkers.

Reply to Discussion

Dealing with Mr. McKinnon Wood's reference to the trailing edge angle, he said that he had been led to go into this as a result of some tests carried out in the high-pressure wind tunnel in America. The maximum lift had fallen off with increasing Reynolds number, and the minimum drag was increased. Looking at the wing section, he had suggested that it must be due to the trailing edge angle. In the C.3 section, there being no necessity to provide sufficient depth for a rear spar, he had been able to follow a Joukowski form more closely and to reduce this angle.

It had to be admitted that in any multi-spar wing capable of resisting torsion, either by virtue of the wing covering or by some internal bracing arrangement, it was possible to vary the load distribution between the spars according to the degree of torsional resistance of the wing. With a two-spar wing of low torsional rigidity it was possible under certain flight conditions for one spar to take nearly all the load. In the case of a multi-spar wing, internally braced, and not relying upon the wing covering for torsional stiffness, it was possible to calculate the correct distribution of load by strain energy methods of considerable complexity. With rigid wing covering, there was no known satisfactory analytical solution.

In putting forward the Monospar system, he (Mr. Stieger) had aimed at making the torsion resistance part of the wing structure, independent from the part which resisted bending. Thereby it was possible to establish confidently the exact amount of load taken by each portion of the structure. Personally, he felt much happier in such a case than in one where the loads were interdependent upon the mutual deflection of component parts of the structure.

With regard to Mr. McKinnon Wood's suggested criterion that the torsional resistance depended upon the enclosed area, it was to be pointed out that in the Monospar arrangement, the distance between the pyramid apices was 60 per cent. of the chord. The enclosed area in this case was therefore $0.3\ tc^2$ (where "c" was the wing chord and "t" the thickness/chord ratio). For two spars of depth $0.9\ tc$ and $0.7\ tc$ and $0.4\ c$ apart, the value would be $0.32\ tc^2$, so that there was not very much difference. Either system could be designed to give torsional rigidity, but the great virtue of the Monospar system was the economic weight for which the wing could be constructed.

Mr. Duncanson mentioned the 3.5° tip deflection required in German design, but he considered that we were not yet in a position to postulate a value which should apply to all monoplane wings. So much depended upon the type of construction, aileron construction for prevention of flutter, and the twist which was allowable before reversal of control occurred. He wished Mr. Duncanson good luck with his tubular spar construction if he was able to do what he had stated in a practical design.

In reply to Mr. Hollis-Williams, he said that one saved roughly 40 per cent. on the wing spars if one left out the rear spar, because the front spar was moved further back, and one could make it stronger for the same weight. With each component part one always had to put on extra weight because of the necessity of working in material of definite size. The more members, the greater the extra weight involved.

As regards the suggestion that the figure of approximately 0.5lbs. per sq. ft. for secondary structure obtained on the Fokker F. VII A. Monospar wing was a product of daring design, there was nothing abnormal about the construction. Specimen ribs had been thoroughly tested and found to be at least 30 per cent. stronger than the maximum requirements, the fabric weight was normal, as were the leading and trailing edges and the stringers. If the extra structural reinforcement required by Mr. Williams on his secondary structure was 100 per cent. of the net weight of that structure, there must be something radically wrong. The 0.5lbs. per sq. ft. gain on the primary structure was due to the single spar construction, this figure representing the weight of a rear spar.

Referring to the vulnerability of military aircraft to gunfire, the probability of hitting a single spar was decidedly the less. If one spar of a two-spar wing were to be shot through to such an extent as to cause its failure, the wing would collapse, so that one was no better off.

He was glad that Dr. Lachmann had mentioned the B.F.W. construction, for he was afraid that in the paper he had given the wrong impression. He had wanted to point out the problem designers were concerned with when adopting that system, *i.e.*, the change from pure shear to tension. With regard to the remarks on differential aileron control, he (Mr. Stieger) had been more concerned in trying to find an explanation for the behaviour of the aileron at high speeds than in considering the yawing moment.

The remarks concerning the calculation difficulties involved in multi-spar wing design were not meant to imply that Mr. Pollard had not realised to the full what he was up against. What he wanted to emphasise, and he had purposely exaggerated the case so as to bring home the difficulties which were likely to be encountered, was the tendency to distortion where the same care had not been taken in design. He (Mr. Stieger) had had in mind, not static conditions, but the behaviour of such a wing in flight where undue distortion might influence the load distribution across the wing section and produce a cumulative effect leading to ultimate failure. In the paper he had pointed out the sequence of events if an equal stress basis was adopted with an idea of reducing the weight as much as possible. He agreed with Mr. Pollard that, in a properly designed multi-spar wing, the developed stress had to be arranged so that the spars deflected by equal amounts so as to preserve the aerofoil section, but one was therefore bound to increase the weight. The 3/1 spar depth ratio had been taken from a Junkers wing and not from the Bristol construction.

The reason for the statement that the Monospar wing was superior to the multi-spar wing as regards immunity from flutter was based on the recommendation of Messrs. Frazer and Duncan in their monograph on "Wing Flutter." It seemed to him that the Monospar wing, taking everything into consideration, was more favourably placed.

On the question of reversal of control, the original reversal speed calculated on a semi-rigid wing assumption had proved to be about 65 m.p.h. To disprove this, the aeroplane in question had given flight demonstrations to the contrary over a speed range of 45 m.p.h. to 200 m.p.h. Ultimately, they had been able to indicate certain wrong assumptions in the theoretical interpretation, and it had become apparent that the Monospar wing would require separate mathematical treatment in order to obtain a correct solution.

In practice, it had been found that 30 per cent. initial tension was a reasonable figure to work to. The torsional deflection was thereby halved as long as the load in the wire did not exceed the value of that initial tension, and this arrangement was found to be satisfactory under flight conditions. An amount of torsion outside this range was rarely experienced and was always of very brief duration, for which a momentary deflection of greater value was not important. There was no vibration on the torsion bracing system as in the lift wires of a biplane, no shock loads since centre of pressure changes were never instantaneous,

and the wires were comparatively short in length, so that the elastic strain was small. Practical experience with the experimental monoplane mentioned in the paper showed that, once adjusted, the wires required no further attention.

Finally, he could not agree that the field for Monospar construction lay with small aircraft only. He was of the opinion that it would be even more satisfactory in the case of large machines.

In reply to Mr. Mettam, he had already indicated in his reply to Mr. Pollard the speed range achieved without reversal of aileron control, and Flight-Lieut. Schofield had answered the question as regards flight with torsion bracing wires removed. The C.P.F. design factor for the Fokker F. VII A. wing was 4.4.

He appreciated the points which Mr. Spencer had brought to the forefront. Referring to heaviness of lateral control at high speeds experienced with a reflex aerofoil section, the response of the aircraft to aileron operation had been particularly noted and found to be both immediate and positive. If there had been any appreciable wing twist, the response was bound to have been sluggish. The heaviness has, therefore, been attributed to the only other logical cause. He, Mr. Stieger, agreed that a rigid wing covering as used in the Junkers design stabilised the wing spar; obviously that was so, otherwise the smaller spar booms would be unable to take any load at all. What he stated in the paper was that the skin did not take a *direct* bending load.

Concerning the remarks on fabric wing covering, no account was taken in the design of any contribution of the fabric towards the torsional stiffness of the Monospar wing construction. Ultimate static tests had shown that undoped fabric increased the stiffness slightly, and that the final doped wing was further improved as regards torsional stiffness. It was apparent that this must always be the case since the doped fabric was bound to act to a certain extent in the same manner as a rigid wing covering. The application of dope remover reduced the wing stiffness figure, but, although the fabric was slackened to the extent of being pronounced unserviceable, it was not possible to bring the torsional stiffness figure back to that obtained with undoped fabric. However, the aircraft had been flown and dived with the wing covering in this condition, and it was not considered that any combination of climatic conditions would cause a greater depreciation of the fabric than had been obtained in this manner.

The Monospar wings so far constructed had all been fitted with mass-balanced ailerons. This had been done because the R.A.E. had insisted upon it, whereas he, Mr. Stieger, was confident that it was not an essential in a wing of this construction, and he had been quite willing to omit this refinement.

In the query on the criterion of torsional stiffness, the figure taken was torsional deflection in degrees of angle per foot span, in view of the fact that over the portion of the wing occupied by the torsion bracing, the relation between span and wing torsion was approximately linear. This did not hold over the tip portion of the wing, and attention was called to Fig. 8 of the illustrations to the paper.

He noted that Mr. Farren was of his opinion that the case for the monoplane had been considerably strengthened in the light of recent developments.

He would refer Air Commodore Chamier to the remarks on secondary structure which he had already made in reply to Mr. Hollis-Williams. Since a secondary structure weight of 0.58 lbs. per sq. ft. had been achieved, this rather upset the percentages alluded to.

Mr. Townshend raised the question of adjustment of the torsion bracing. As intimated earlier, there was practical evidence that, once adjusted, the Monospar wing needed no attention. If occasion did arise, faulty rigging would at once show itself on the wing incidence, since the structure was non-redundant. The torsion bracing system being quite simple, it was very easy to decide which wires to adjust to make good the discrepancy.

No trouble had been experienced with the fabric covering of the reflex portion of the wing. The fact that depth towards the trailing edge of the section was not required because of the absence of a rear spar had made it possible to achieve the reflex much more gradually than was usual.

In reply to Mr. Carter, in the paper he had definitely stated " the Ford wing relies upon the metal covering for torsional stiffness." Mr. Carter's remarks implied that he had confused strength with stiffness. He, Mr. Stieger, fully realised that the Ford wing depended upon its internal structure for torsional strength, but this did not prevent the wing covering from increasing the torsional stiffness very appreciably. Fabric covering did this also, but by no means to the same extent.

He could assure Mr. Shenstone that the type of wing root indicated in Fig. 10 on the paper together with a wash-out of incidence from the point on the wing where the " thinning-down " commenced, had been shown in flight tests to have completely eliminated tail buffeting. He noted with interest the formula given by Mr. Shenstone as a wing flutter criterion.

PROCEEDINGS

Eighth Meeting, Second Half, 67th Session

The Eighth Meeting of the Second Half of the 67th Session of the Royal Aeronautical Society was held on Thursday, 14th April, 1932, at 6.30 p.m., in the Lecture Hall of the Royal Society of Arts, 18, John Street, Adelphi, W.C.2.

Mr. D. R. Pye was in the chair, and a paper, entitled "Aero Engine Accessories," was read by Mr. W. L. Taylor, A.F.R.Ae.S.

The Chairman: The aero engine was in most of its essential features very much the same as the engines driven in motor cars, even down to the accessories, such as water pumps and oil pumps, but there were certain special conditions under which the aero engine operated which set it apart in a class by itself. It was the great variety of specially designed features to meet those conditions with which Mr. Taylor was going to deal. He (the Chairman) did not think there was any need to introduce Mr. W. L. Taylor to people connected with the aircraft industry. The lecturer had had a very wide experience as an engineer before he took to aero engine work, and since the War had been in a responsible position at Farnborough connected with the development of aero engines.

AERO ENGINE ACCESSORIES

BY

W. L. TAYLOR, A.F.R.Ae.S.

Since the Armistice the gradual development of the various types of aero engines, together with the abandonment of windmill driven accessories, has necessitated an increase in the number of auxiliaries incorporated in the engine structure, and the engine designers are to be complimented for the ingenuity and compact arrangement of the auxiliary drives and housings on present-day aero engines.

The auxiliary drives for valve operation, dual magnetos, oil pressure and scavenge pumps, water and petrol pumps, supercharger, turning, starting and gun gears, are usually grouped in a housing or housings at the rear of the engine, except that on the radial air-cooled engine the valve gear is arranged at the front and the water pump is unnecessary. Variations in the positions of certain components do occur, however, but the types of many components have changed but little, if at all, in technical detail since that date. On this account the more recent accessories only will be reviewed.

Figs. 1 and 2 illustrate the rear assemblies on modern air- and water-cooled aero engines.

The most important addition to engine accessories of recent years is the supercharger to maintain a constant pressure in the engine induction pipe up to a prescribed altitude, expressed in recognised terms as "rated boost pressure" up to "rated altitude."

Except for take-off purposes and on racing engines, induction pipe pressures in excess of 14.7 lb./sq. inch absolute are not, as yet, commonly used on Service and civil engines.

The several superchargers available have been described by Mr. A. H. R. Fedden before the Royal Aeronautical Society in 1927 (see Proc., Vol. XXI).

The geared centrifugal type capable of maintaining a rated boost pressure in the engine induction system at rated altitudes up to 12,000 feet, is to-day the type fitted to both water and air-cooled engines by the respective British aero engine firms.

Armstrong-Siddeley supercharged " Jaguar " engines with this type of compressor were undergoing flight trials during 1922. The experience gained with various types of impeller, diffuser blades and ball bearings at high rotational speeds, during the development of the exhaust driven centrifugal blowers for

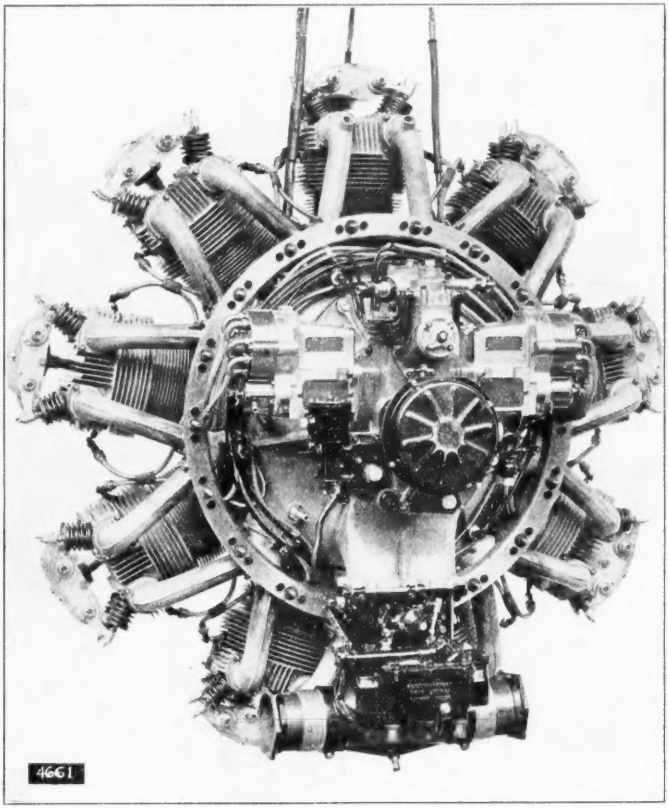

FIG. 1.
Rear of Pegasus engine.

" Liberty," Napier " Lion," Bristol " Jupiter," and Rolls-Royce " Condor " engines, together with the improvements in cylinder design and materials contributed, in the main, to the success attending the later production of the geared centrifugal type by these manufacturers in 1927.

The centrifugal type compressor gives a continuous delivery flow and as the pressure rise and delivery are functions of the rotational speed its dimensions can be small by virtue of the high rotational speeds possible.

The construction, typical of this class of compressor, is illustrated in Figs. 3 and 4. The casing is split in a vertical plane, one part carrying the inlet volute or bend, the other the diffuser vane ring and discharge volute or annulus.

The impeller is either of steel or duralumin, and if of the latter material, is fully shrouded on one side for strength. The number of blades used varies from 10 to 18. To convert the kinetic energy imparted to the mixture on its passage through the impeller into pressure energy, a number of stationary channels, formed by the diffuser vanes, are arranged around the periphery of the impeller at an angle coincident with the path taken by the mixture on leaving the blades.

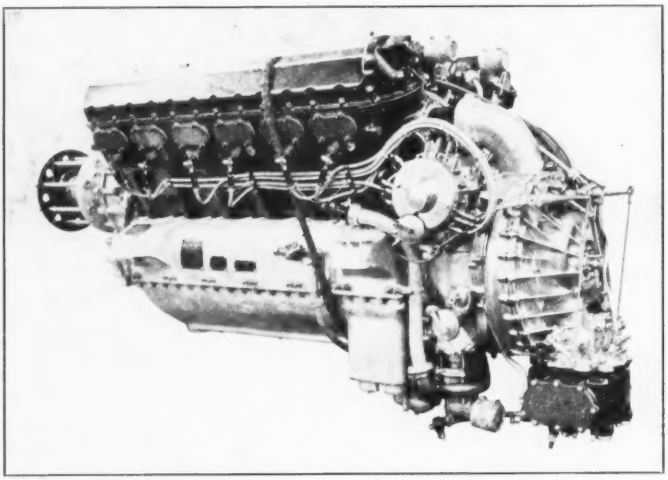

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FIG. 2.

Rear of Kestrel H.M.S.

For high mixture velocities, such as obtain in this type of compressor, a diffuser chamber is necessary if a high efficiency is to be obtained from the unit. Vanes are not essential and the diffuser channel may take the form of a spiral volute or plain annulus, but an increase in the length of the diffuser path is necessary.

In the gear train, a spring drive to the primary gear wheel and slipping clutch pads in the triple lay shaft driver wheels are incorporated, to minimise the heavy stresses imposed in the train by sudden engine accelerations and by torsional vibration, and also to equalise the tooth pressures.

These adverse effects increase as the rated altitude is increased, owing to the necessity for higher gear ratios or larger impellers, thus increasing the inertia of the rotating parts and adding to the acceleration loads.

In this country the carburettor is placed on the inlet side of the compressor —a position which affords neatness and simplicity and obviates the necessity of balancing the fuel and induction systems.

As the duty of the supercharger is to supply the engine at its rated altitude with a weight of air approximately equal to that which could be inhaled naturally at ground level, its displacement must be in excess of that of the engine. Thus

at lower altitudes the intake must be throttled or the surplus air valved to atmosphere, if the rated boost pressure is not to be exceeded. Valving to atmosphere is not permissible if the carburettor is placed on the blower intake, as fuel would be wasted thereby, nor will valving give any advantage in reduction of power absorbed by a centrifugal compressor if used with a pressure carburettor, as the work of compression is already completed entirely in the blower.

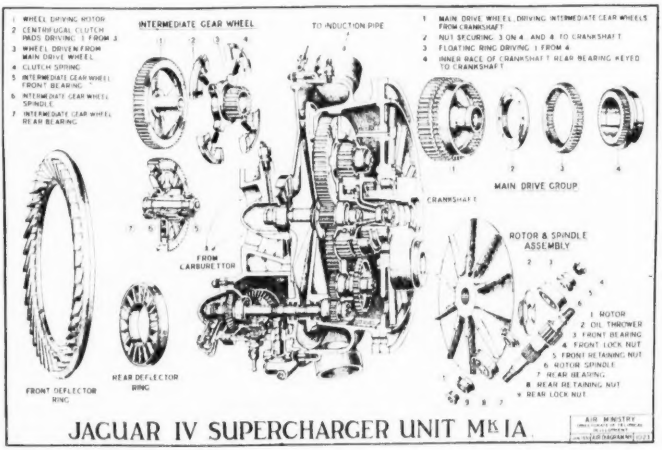
1 WHEEL DRIVING ROTOR
2 CENTRIFUGAL CLUTCH PADS DRIVING 1 FROM 3
3 WHEEL DRIVEN FROM MAIN DRIVE WHEEL
4 CLUTCH SPRING
5 INTERMEDIATE GEAR WHEEL FRONT BEARING
6 INTERMEDIATE GEAR WHEEL SPINDLE
7 INTERMEDIATE GEAR WHEEL REAR BEARING
INTERMEDIATE GEAR WHEEL
TO INDUCTION PIPE
1 MAIN DRIVE WHEEL DRIVING INTERMEDIATE GEAR WHEELS FROM CRANKSHAFT
2 NUT SECURING 3 ON 4 AND 4 TO CRANKSHAFT
3 FLOATING RING DRIVING 1 FROM 4
4 INNER RACE OF CRANKSHAFT REAR BEARING KEYED TO CRANKSHAFT
CRANKSHAFT
MAIN DRIVE GROUP
ROTOR & SPINDLE ASSEMBLY
FROM CARBURETTOR
1 ROTOR
2 OIL THROWER
3 FRONT BEARING
4 FRONT LOCK NUT
5 FRONT RETAINING NUT
6 ROTOR SPINDLE
7 REAR BEARING
8 REAR RETAINING NUT
9 REAR LOCK NUT
FRONT DEFLECTOR RING
REAR DEFLECTOR RING
JAGUAR IV SUPERCHARGER UNIT MK IA
AIR MINISTRY

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FIG. 3.

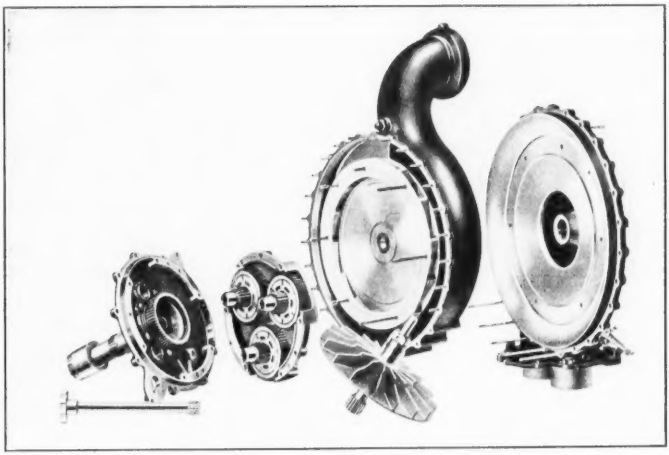

FIG. 4.

Kestrel supercharger (exploded view).

Throttling the engine during a climb at constant rotational speed does not reduce the temperature rise of the mixture due to compression, and as is probable, hot air intakes and heater muffs are fitted to the carburettor to prevent freezing of diffusers and throttle valves, the engine is handicapped more severely

than is necessary, from the points of view of temperature and blower input power, at all altitudes below full throttle height.

Positioning the carburettor on the delivery side of the compressor would obviate the use of heaters to overcome the freezing troubles and so allow a reduction of the mixture temperature, but adds to the installation difficulties and requires a separate control valve on the compressor intake.

In a displacement blower of the " Roots " or " Powerplus " type, no work of compression as such is done in the blower itself, flow back from the overcharged induction system compresses the delivery from the rotor pockets, so that this type, with a carburettor on its delivery side and intermediate by-pass valves, lends itself to valving surplus air with a minimum temperature rise and loss of power.

On account of the low rotational speeds of this type its consequent bulk and weight are against its adoption for altitudes of the order of 12,000 feet, especially on radial air-cooled engines where the crankcase shape and induction system accommodate the centrifugal type so conveniently. Instead, multi-speed gears giving at least two ratios are being developed for use with the latter—the lowest ratio for duty at the lower altitudes to reduce the temperature effects and improve the power output.

Should the variable pitch airscrew be adopted, the operational disadvantages of the geared centrifugal compressor will be magnified, and an effort to overcome the installation difficulties of the displacement type might be worth while, as this type is better adapted to full throttle heights of 20,000 feet, so far as performance alone is concerned, than the geared centrifugal type.

To compare the merits of these two types of compressors operating at a rated altitude of 12,000 feet, the following data is appropriate.

Depending on the rated boost pressure, the centrifugal type would have a compression ratio of the order of 1.5 : 1 and an impeller tip speed of 850 ft./sec., whilst nominal values for the impeller rotational speed, gear ratio and adiabatic efficiency (compressing air only) are 22,000 r.p.m., 10 : 1 and 65 per cent. respectively. When built into a radial engine of 465 b.h.p. at rated altitude, its weight would approximate 35lb.

A " Roots " displacement type would probably rotate at not more than 4,000 r.p.m. (rotor speed), have an adiabatic efficiency of 80 per cent. at 1.5 : 1 compression ratio, and weigh 85lb. for the same engine.

The " Roots " with by-pass valve fully open requires 6 h.p. to drive it on the ground and the centrifugal under throttled conditions 19 h.p., while the temperature rise due to compression (air only) is 7°C. with the former and 41°C. with the latter.

At engine " take-off " revolutions, the extra airscrew shaft power available with the displacement blower is 40 h.p.; under full throttle height conditions 15 h.p.

At compression ratios higher than 2 : 1, the " Roots " type does not, however, function as efficiently as the " centrifugal," so that, though it holds operational advantages up to altitudes of 18,000 feet, the centrifugal with an exhaust turbo drive is the solution for rated full throttle heights of 20,000 feet and above.

An interesting feature in the development of superchargers has been the performance of ball bearings at high rotational speeds.

The bearings carrying the impeller shaft in a centrifugal compressor may rotate at speeds in excess of 30,000 r.p.m. and require special consideration from the points of view of loading, assembly limits, cage material and method of mounting, quantity of lubrication and range of temperature of operation. In the R.A.E. designs of compressor the bearings support a very slight radial load amounting to from 8 to 11lb. for the turbo drive and 5lb. for the gear drive. An extra wide type double row ball bearing, 20 mm. bore, is used to locate the impeller shaft. No modifications of the makers' standards have been required

to obtain a life of 500 hours and over, but for bearings of 30 mm. and 55 mm. bore, the largest sizes used for turbo and gear drive respectively, this type has proved quite unsuitable. Of the various single row type bearings with cages centred on the inner race, on the outer race and on the balls, the most satisfactory results obtained have been from a single row bearing without a filling slot, with a cage split circumferentially, centred on the balls and riveted between each ball. The cage is given a radial " float " of 8 to 10 thousandths of an inch for the turbo drive and 4 to 5 thousandths for the gear drive to meet the temperature effects; the materials used are a hard bronze for use with bearings on the former drive and duralumin for the latter.

The quantity and method of supplying the lubricating oil is important. An excess of oil gives high cage drag and contributes equally with too meagre a supply in causing bearing failures. Cage drag is combated by employing an increased number of balls smaller than standard, shallower ball tracks, close shrouding of both sides of the bearing, and free drainage of all oil that has passed through it.

At the R.A.E. the practice is to meter quarter to half a pint of oil (under engine operation conditions of pressure and temperature) per bearing per hour.

This quantity is not considered excessive and does not adversely affect the engine performance, or the conditions of the combustion chamber, valve stems, etc.

Automatic Boost Control

With the installation of supercharged engines in Service aircraft, the need became apparent for a reliable unit to adjust automatically the pressure in the engine induction system at all altitudes and attitudes of the machine below full throttle height to protect the engine from abuse and relieve the pilot of giving constant attention to the boost gauge and to the throttle adjustment.

Fig. 5 shows the first experimental R.A.E. model adapted by Messrs. Armstrong-Siddeley to a " Jaguar IV " engine.

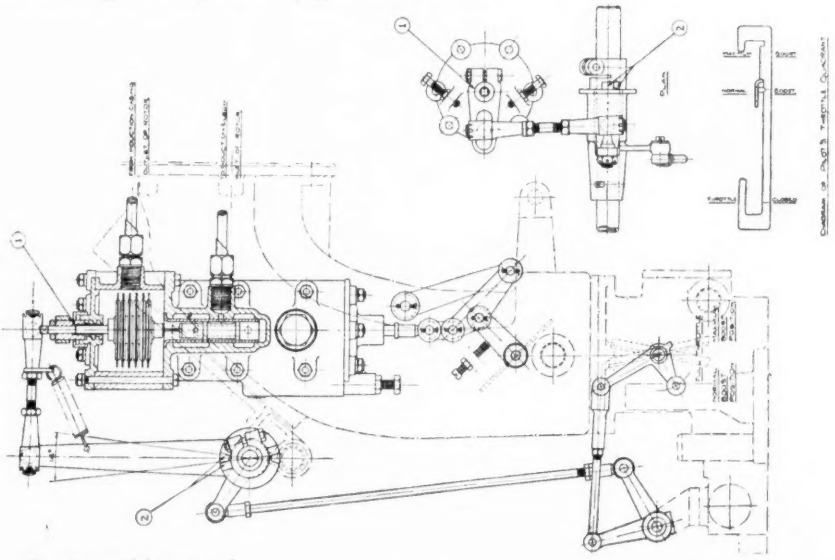

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FIG. 5.

Arrangement of alternative boost control.

The principal components of the control are, a piston valve controlled by a battery of evacuated aneroid capsules exposed to the induction boost pressure, and a servo cylinder and piston operating an auxiliary throttle in the compressor intake bend. A dashpot or dashpot effect to damp out any tendency to hunt is embodied.

The servo control is operated by the difference of pressure obtaining in the supercharger inlet and delivery branches. Any increase or decrease of the rated boost pressure collapses or allows expansion of the aneroid capsules and operates the piston valve to which they are linked, permitting the boost pressure to communicate with the servo piston and operate the auxiliary throttle in the correct sense.

The closing movement of the auxiliary throttle is limited to that giving the desired induction pipe pressure at " take-off " r.p.m., so that under any conditions of failure of the unit the pilot has full ground power at his control.

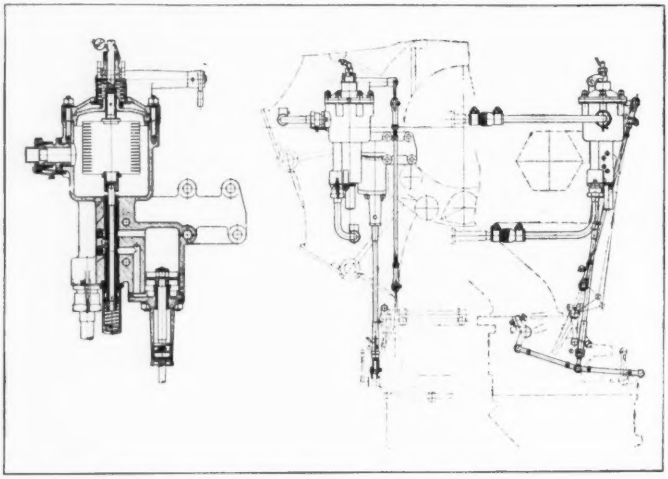

FIG. 6.

Boost control on Pegasus, oil-operated.

Variations in the operation of the servo control by oil pressure and the main throttle valve by toggle or cam mechanisms are employed on the several models of aero engines.

Owing to the lower performance on and near the ground of the constant induction pressure type engine with a fixed airscrew compared with a corresponding naturally aspirated engine, it is advantageous to operate the former at a higher than normal induction pressure for short periods as when " taking-off."

To obtain regulation at the increased boost, the capsules are moved by a suitable mechanism to another position, to compensate for the amount they collapse under the increase of induction pressure in order that the controlling piston valve may be maintained in mid-position over the servo cylinder ports. The throttle quadrant in the cockpit is fitted with a gate to locate the position for normal boost, and movement through the gate brings maximum boost into operation until such time as the throttle is pulled back or the altitude to which the blower can maintain the high boost is exceeded.

To assist the engine in meeting the more severe operating conditions an interlinkage for enrichment of the mixture during the period of operation at maximum boost is provided.

In the particular aircraft in which the device was tested, 1½ lb./sq. inch increase in boost pressure resulted in an increase in engine r.p.m. of 60 and an increase of 340 ft./minute in the rate of climb at 1,000 feet altitude and climbing at an A.S.I. of 70 m.p.h.

Fig. 6 illustrates the unit fitted to " Bristol " engines. The serbo piston is oil operated—the oil being conveyed from the engine lubricating system through internal passages in the main casting.

Automatic Mixture Control

The pressure servo control as applied to boost regulation has also been adapted to control mixture strength under varying conditions of flight, in order to obviate the undue wastage of fuel experienced with the present manual control.

Tests in a squadron flying in formation at 15,000ft. demonstrated that a saving of fuel amounting to approximately 30 per cent. was possible, and also that the range of a squadron could be estimated more correctly if the variation in fuel consumption between similar aircraft could be reduced.

The adaptation of the aneroid controlled servo for this purpose postulates that the carburettor shall have a throttle characteristic giving optimum mixture strength over the " cruising " range, so that the control has to function in accordance with height only. A pump and power jets are incorporated in the carburettor to provide for acceleration and the desired increase of mixture strength at full throttle respectively.

Several types of carburettors have been developed to have these characteristics and when fitted with a servo control to operate the altitude control cock incorporated in the carburettor, have given very satisfactory results in flight.

This servo control (Fig. 7) is operated by oil pressure, but has in addition a " follow up " gear to correlate the movements of the control piston and the aneroid capsules, and a manual control to put it out of action if necessary.

Flame Traps

The elimination of the risk of fire in aircraft due to a backfire through the induction pipe has been long sought for, especially since the introduction of superchargers. The installation of a flame trap between the carburettor and the cylinders and as near the engine inlet ports as possible, would reduce the violence of the explosion by extinguishing the flame at its source, and would ensure that no explosion could occur either in the carburettor or inside the supercharger. This surety rules out the consideration of placing the trap on the intake to the carburettor.

In the construction of a " cooling pack " for this purpose, its strength to resist distortion, due to temperature or to the violence of the explosion, and its resistance to the passage of mixture, are also of importance.

The final form of trap fulfilling these conditions is illustrated in Fig. 8, though circular forms of this type are also used.

This form of corrugation and construction affords the greatest strength, from thin material, to resist distortion by heat or explosion pressure, consistent with the lowest resistance to mixture flow.

The material used is preferably stainless iron in strips 1in. wide by .0015in. thick with an inside corrugation measurement of .023in.

The resistance to mixture flow and reduction of engine performance have proved on bench tests of engines to be negligible. Flame traps have also been tested in flight on supercharged engines with satisfactory results. Fig. 9 illustrates the installation of traps on the inlet ports of a " Kestrel II.S " engine.

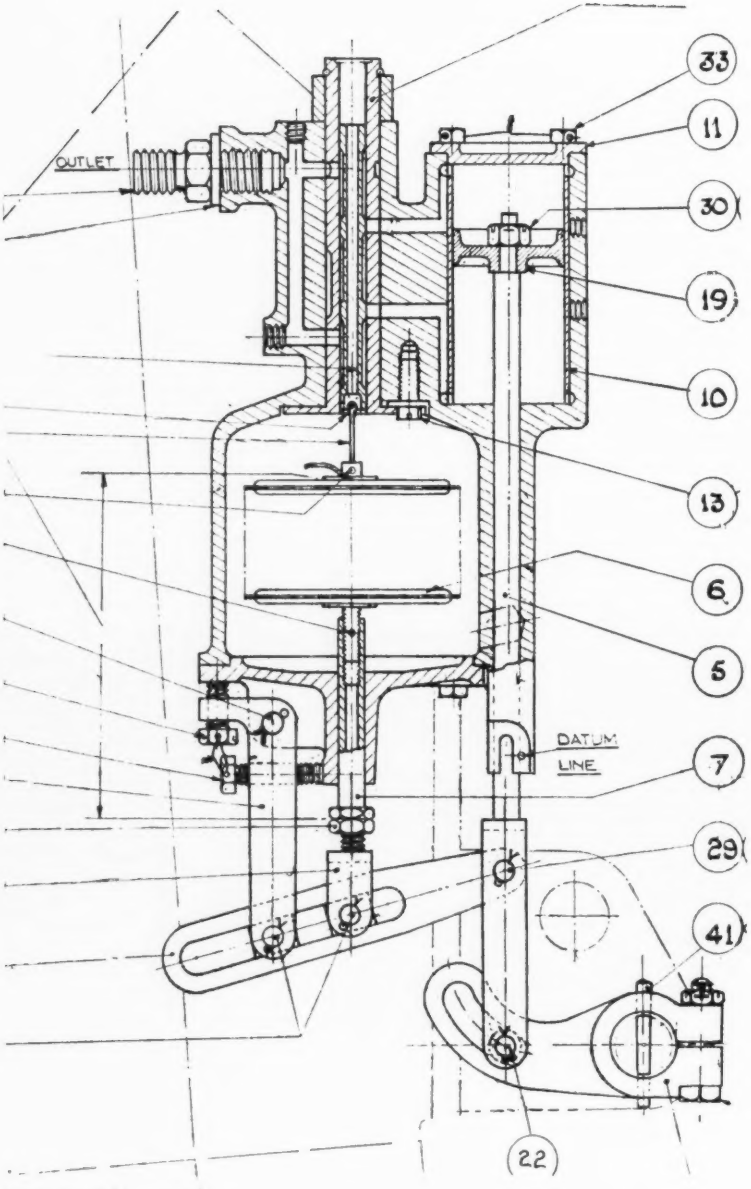

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FIG. 7.

R.A.E. automatic altitude control.

On engines fitted with an effective induction pipe flame trap it should be permissible for the carburettor air intake to be placed inside the engine cowling with the following advantages:—

(1) Intake conditions would be stabilised for all attitudes of flight and in consequence a more equable power output obtained than is possible with external air intakes.
(2) Balancing of the carburettor would not present the same difficulties.
(3) Distribution would be improved.
(4) The ingress of sand and other substances injurious to the engine could be prevented more easily.

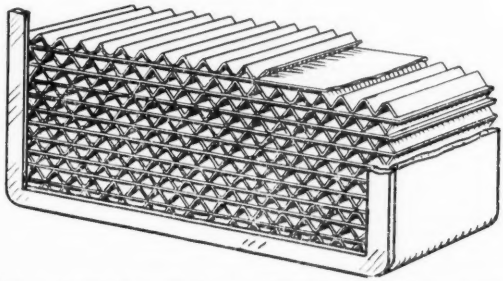

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FIG. 8.

Flame trap.

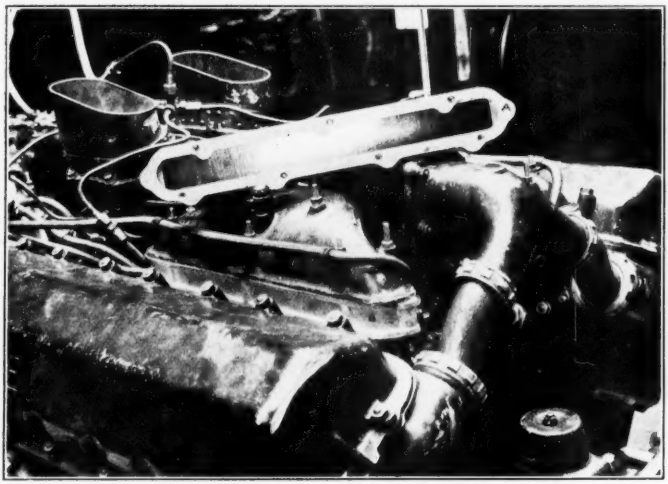

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FIG. 9.

Flame trap on Kestrel.

Magnetos

It is clear that the increased performance of modern high speed engines, either of the high compression, supercharged, or ground boosted types, could not have been attained without adequate ignition systems.

The contemplated engine speeds of 3,000 to 4,000 r.p.m., corresponding for a 12-cylinder engine to magneto speeds up to 6,000 r.p.m., have increased greatly the severity of the working conditions for the magneto and call for special considerations in its design, particularly of the contact breaker mechanism.

Balanced rocker arms of duralumin, special cam contours and the correct spring pressures to prevent " fling " have permitted magneto speeds of 7,000 r.p.m. for short life racing engines and at 5,500 r.p.m. afford a life in excess of 500 hours.

The magneto, with a rotating shuttle wound armature giving two sparks per revolution, has been superseded on all Service aero engines by the polar inductor type giving four sparks per revolution, thus halving the necessary magneto speed.

The use of cobalt steel magnets in place of tungsten steel has afforded a considerable saving in weight owing to the remarkably high magnetic characteristics of the former; for a given duty approximately one-third of the bulk of tungsten steel magnets is required.

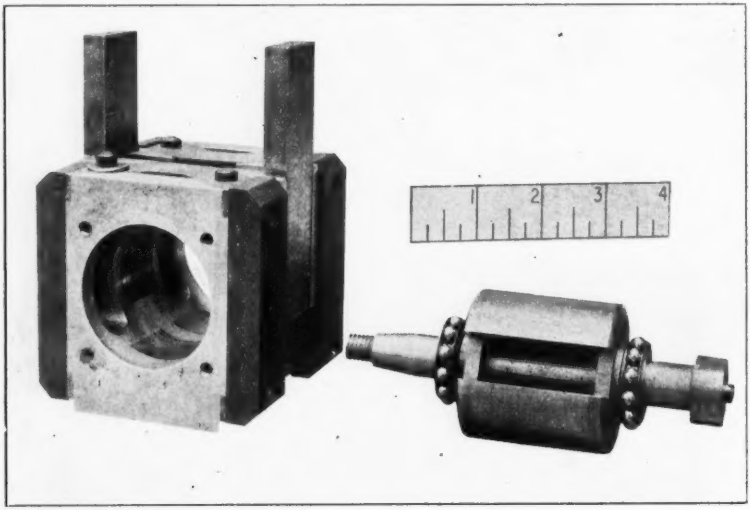

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FIG. 10.

Inductor and tunnel Watford magneto.

The general increase of engine speeds has necessitated the provision for greater mechanical strength of the magneto components to withstand the destructive vibration effects and prevent failure of flange mountings, distributor gears and rotors.

The introduction of " bonding " and " screening " of aircraft magnetos to prevent interference with wireless apparatus not only increases the bulk of the magneto, but also increases the distributed capacity in the high tension circuit and impairs efficiency particularly at low speeds. This effect has been met by improvements to the design of the magnetic and electrical circuits. The use of synthetic resin compounds such as Bakelite provides lightness as well as a high surface discharge voltage, whilst a moulded fabric material such as Textolite provides a light, wear-resisting material for gear wheels and contact breaker heels.

In a particular type of modern polar inductor magneto, two pairs of cobalt magnets are used, each pair feeding a separate iron circuit. The coil is stationary and mounted immediately above the inductor tunnel. A fixed contact breaker is provided, operated by a four-point cam. Distribution is effected in the conventional manner through the gear wheel spindle. Usually the flux changes are brought about by the rotation of two pairs of inductor bars, each pair being of constant polarity with respect to the magnets, but recently an improved type of inductor member (Fig. 10) in the form of a hollow sleeve cut into two segments separated by a longitudinal gap of about 5/8 inch, has been introduced. The segments are composed of soft iron laminations riveted to the spindle end plates. The polarity of the two inductors per revolution is not constant with respect to the magnets as in the other type, but changes each half revolution; alternate sparks at each quarter revolution are of positive and negative polarity respectively.

A diagram (Fig. 11) depicts in skeleton form the magnetic circuit and the position of the inductor with relation to the pole shoes at each quarter revolution.

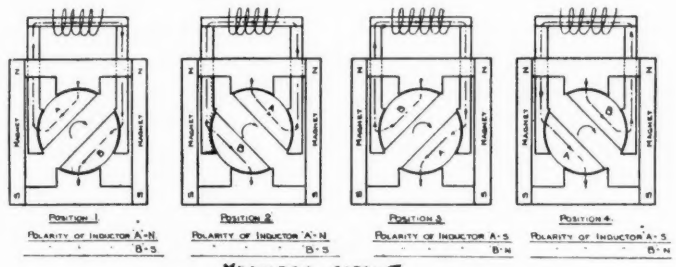

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FIG. 11.

Magnetic circuit, Watford inductor.

The present-day Service engine operates with a sparking plug voltage very rarely exceeding 7,000 volts, but the test schedule for magnetos calls for endurance and type tests at 9,000 volts. This voltage is imposed to ensure that the armature will satisfactorily withstand the increased strain in the windings resulting from high voltage and the internal brush discharges under reduced air density conditions, which ultimately cause deterioration of the insulation of the windings.

Improved methods of constructing and impregnating the armatures to avoid the formation of air pockets in the insulation have considerably reduced these ill-effects.

A recent magneto development to meet the increased number of engine cylinder arrangements in which two cylinders fire simultaneously, is the double-ended secondary winding giving eight sparks per revolution from four breaks and therefore firing two plugs simultaneously. The ignition leads from the twin terminals are led to plugs in the separate cylinders firing together to preserve the dual ignition conditions if one magneto fails.

The Watford Duplex S.P. 8-8 magneto (Fig. 12), which has sixteen H.T. terminals and a hand starter terminal is representative of this type. Its weight is $17\frac{3}{4}$lb.

Now that the low speed sparking characteristics of the modern aero magneto have been improved sufficiently to provide the required starting facilities, the

choice between magneto and coil ignition systems would appear to depend more on considerations of reliability, R./T. interference, weight and fire risk than on the main factor of spark intensity.

The reliability of aircraft magnetos has reached a degree scarcely to be expected of a coil system (however reliable the coil itself might be) because it comprises four different units, coil and distributor, generator and battery, all separated from one another, whereas the magneto is self-contained. This latter factor also admits of easier isolation and more perfect screening to avoid interference with the radio telephone equipment.

The evaluation of the relative weights and fire risk of both systems involves considerations of equipment such as types of engine starter and generator drives, and the general electric services to be provided for in the aircraft.

One decided advantage of the coil system is the greater range of ignition timing procurable.

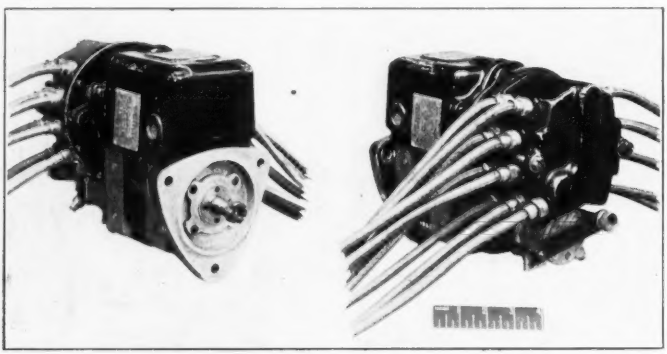

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FIG. 12.

Watford duplex S.P. 8-8 magneto.

Automatic Ignition Control

At present the various models of this device, as fitted to Service aero engines, consists of a " governor " type gear in the magneto drive coupling to vary the ignition timing in relation to the engine speed. (Fig. 13.)

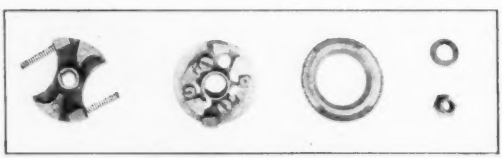

FIG. 13.

Automatic ignition advance coupling (Bristol).

The driving member carries two loaded pivoted arms with rollers which bear on two specially shaped cams on the driven member, with which they are kept in contact by two springs.

As the engine is accelerated the weighted arms move outwards, and in so doing advance the magneto shaft in respect to the driving shaft to the extent permitted by the contour of the cams.

This method is superior to the cheaper and more usual method of varying the position of the " break " relative to armature position, in that it permits the breaker points to separate always in the optimum position with regard to the magnetic field.

The above device does not easily comply with the requirements of maximum advance under throttled cruising conditions, and a system utilising the boost control servo mechanism operated by the induction pipe pressure, with a lost motion or " cut out " for idling and acceleration conditions at the lowest throttled openings, has been devised by one firm of aero engine builders. The application of automatic controls for regulation to the required degree of induction pressure, mixture strength, and ignition advance is an endeavour to retain the simplicity of one engine throttle control for the pilot and also to ensure optimum engine operation under all conditions of flight.

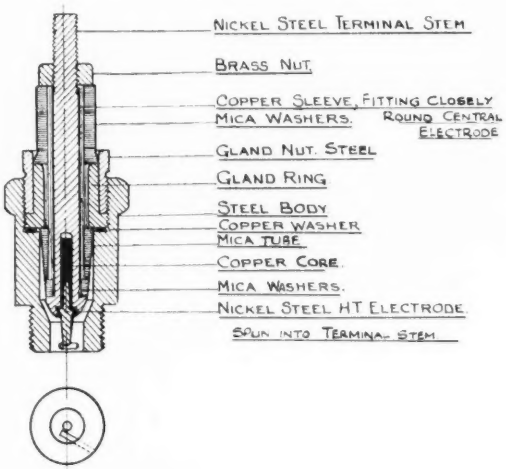

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FIG. 14.

Section of Lodge plug.

Sparking Plugs

The construction of sparking plugs to meet the varying operational conditions of high duty engines is complicated by the opposing conditions which obtain at low and high rotational speeds.

At high speeds the problem is to prevent the central electrode, or earth point, reaching such temperatures as produce pre-ignition, whilst at low speeds under throttled conditions the avoidance of oiling-up is the main consideration, especially in radial and inverted type engines. The ability of the plug to cope with these two extreme conditions depends upon the shape and dimensions of the gas space in the plug body and also on the material and disposition of the electrode. The reduction of gas leakage through the insulation of the plug centre has an important effect on keeping the plug cool and preventing failure through over-heating, with consequent pre-ignition.

The employment of a steel sleeve crimped on the mica wrappings of the central electrode has reduced gas leakage to a negligible amount and, together with a composite construction of the central electrode, has been mainly responsible for the recent satisfactory performances of boosted engines. (Fig. 14.)

In one particular type of electrode construction, to obtain good conduction of heat the electrode is composed of a steel stem sheathed in a copper sleeve and having a cylindrical copper inset immediately behind the nickel spark inset.

Nickel alloy electrode tips give the highest resistance to erosion resulting from the arcing effect of the electric discharge and gas swirl. The use of quartz and porcelain for insulating purposes has not afforded as satisfactory results as mica for high duty plugs, owing to brittleness and the difficulty arising from different expansion coefficients of the materials—in obtaining a gas-tight joint in the electrode stem by cementation or grinding.

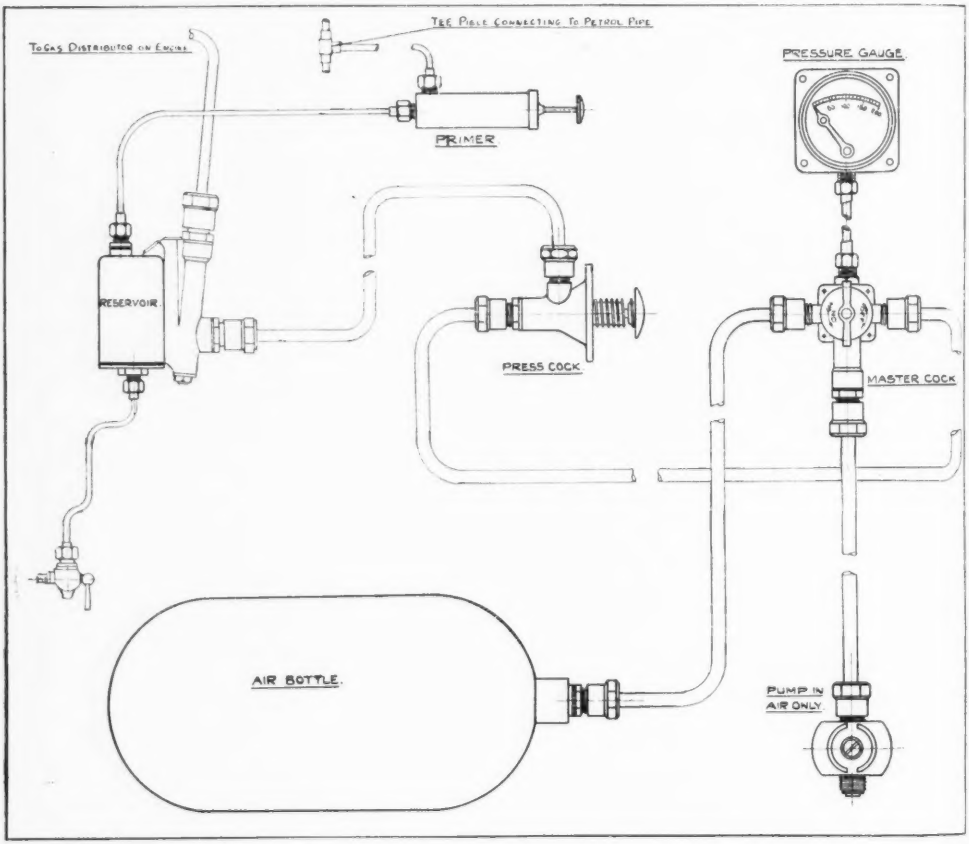

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FIG. 15.

R.A.E. Mark II. starter system.

Starters

Several types of war-time engines were equipped with air distributors and induction manifold priming jets to provide easy starting facilities, but the results were indifferent, due to faulty mixture strength, leaky components, and weak magnetos. Hand turning methods, in conjunction with hand priming, and hand starter magnetos were also used.

Gas Starting

It was not until the end of the war, when the late Major Norman, R.A.F., decided to distribute mixture under pressure to the several engine cylinders through spring-loaded non-return valves, that satisfactory self-starting of engines of the largest output was obtained. The system is known as the R.A.E. gas-starter system Mark I. The starter unit comprises a small two-stroke power cylinder and a pumping cylinder, which takes its supply of mixture from a small carburettor set to give a mixture richer than normal to compensate for the deposition of fuel in the distributor pipe lines.

The delivery of the mixture to the cylinders, via a rotating disc distributor valve, is controlled so that the mixture is supplied in sequence first to those cylinders beginning the firing stroke and secondly for a part of the induction stroke. The mixture is supplied under varying pressures up to 150 lb. per sq. inch.

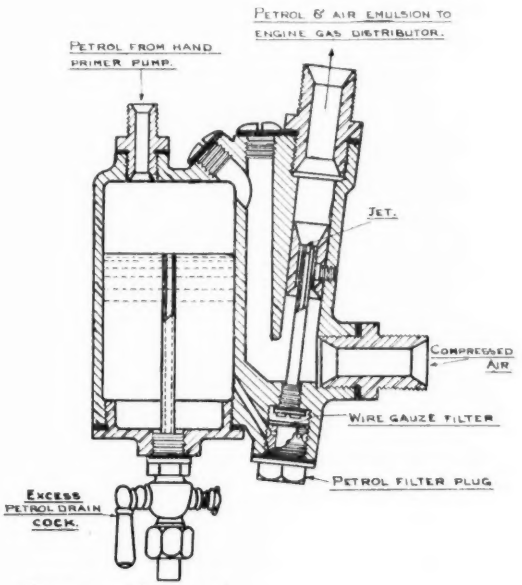

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FIG. 16.

Auxiliary carburettor starter system.

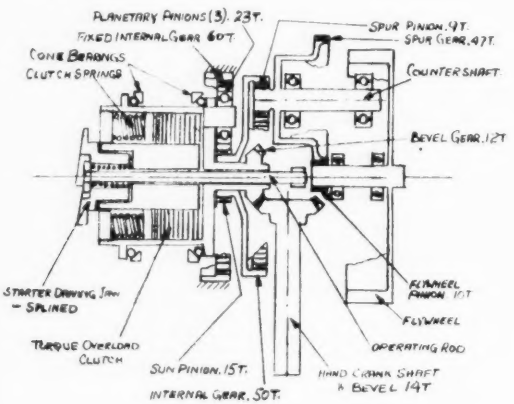
A two-cylinder type magneto is fitted—the second ignition lead being connected to the distributor of the main engine magneto. This lead is short circuited until the engine is turning freely, and on the opening of the switch the engine fires and picks up from its own carburettors and magnetos. The starter weighs some 50 lb., has the advantage that its location away from the engine does not impair its action, and is installed either in large aircraft or on trolleys for aerodrome purposes.

An improved form of this starter unit is known as the Bristol gas starter.

To provide starting of engines in aircraft where weight and bulk are serious considerations, systems known as the R.A.E. Mark II. (Fig. 15), "Heywood," "Viet," etc., are available. The gas distributor valve and cylinder non-return

valves are retained, but the starter unit has been replaced by high pressure air bottles, charged either on the ground or in the air from an engine-driven pump or hand pump. On pressing the starter valve the high pressure air passes through a subsidiary carburettor (Fig. 16) without a float to pick up a measured quantity of fuel, and is then distributed to the cylinders in firing sequence.

The induction system is not primed from the rotating distributor valve, but if desired from a small hand primer. A hand starter magneto is advisable, and is usually fitted. The air bottle pressure is of the order of 200 lb./sq. inch, and four or five starts are possible in the field. The weight varies from 12 to 18 lb., and everything is carried in the aircraft. This system, due to its light weight, is particularly suitable for single-seater fighters, and is easily operated by the pilot from the cockpit.



DIAGRAMMATIC VIEW OF ECLIPSE SERIES 6 INERTIA STARTER

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FIG. 17.

Inertia Starters

Recently inertia starters embodying either a hand crank or electric motor, with a gear train to energise a small flywheel of some $3\frac{1}{2}$ to 6 lb., together with a constant torque slipping clutch to transmit the flywheel energy to the crankshaft, have been introduced. The gear ratio is generally 150: 1, and when the revolutions per minute of the flywheel have reached approximately 10,000 a tripping device engages the starting dogs and at the same time connects the flywheel through the gear train (Fig. 17) to the clutch.

The starters, of which the "Aeromarine" and "Eclipse" are typical, weigh between 19 and 30 lb.

The disadvantages of these starters is that hand cranking is not entirely practicable on wing-engined machines, or on single-seater aircraft, without assistance.

The electric energised type is attractive from many points of view excepting for the high weight of the special heavy duty battery required.

The Herzmark direct acting compressed air starter (Fig. 18) is mounted concentric with the crankshaft, to which it transmits the energy for starting by means of dogs. It consists of a closed cylinder, housing two pistons placed face to face, having integral concentric tail rods on which are cut multiple quick-pitch

screw threads, the pistons being in the same relation to one another as a bolt and nut. The male piston on its opposite face has an extension to carry the starting dogs, whilst the external surface of the tail rod on the other piston is splined through the cylinder cover to prevent rotation.

The pistons are held close together by means of an internal tension spring. Compressed air at the required pressure up to 500 lbs./sq. inch is introduced between the pistons, forcing them apart, when the inner piston is caused to rotate by reason of the multiple thread, as the outer splined piston moves axially along its stroke. A stroke to give one to $1\frac{1}{3}$ revolutions of the crankshaft is provided, but, owing to the acceleration of the engine up to 500 r.p.m., and the consequent inertia of the moving parts, two or three further revolutions are obtained during which time the magnetos and carburettors come into operation.

This type of starter is successful in starting compression ignition engines of 500 h.p. The necessary air bottles are charged from an engine-driven air compressor which automatically ceases to pump when the designed bottle pressure is reached.

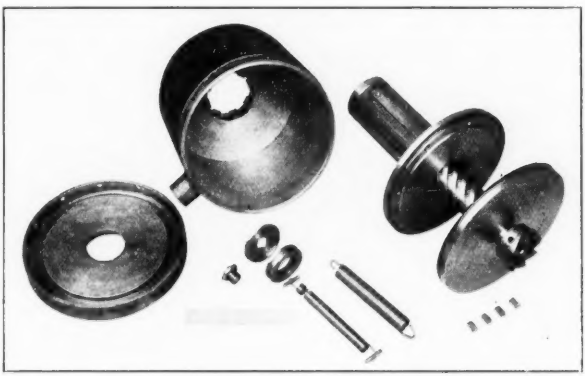

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FIG. 18.

Herzmark.

Cartridge Starters

The Farman cartridge starter (Fig. 19) consists of a breech and bolt mechanism to take the cartridge containing the combustible which burns at a predetermined rate. The firing chamber is mounted on one cylinder of the engine and discharges to the cylinder through a spring-loaded non-return valve.

It is necessary to turn the engine until the correct piston has just commenced the firing stroke. The trigger can be operated from the pilot's seat, and the effect on the piston is to give it a " push " instead of a blow. The starter is probably the lightest it is possible to employ, and a supply of cartridges is easily carried. It has inconveniences if used with wing engines, whilst on engines with enclosed valve gear and an " odd " airscrew shaft reduction ratio, some external device to indicate the correct piston position is necessary. There is also the danger attached to the movement by hand of the airscrew on a warm engine.

It seems that a compressed air or mixture system is likely to meet most installation conditions, and this view is supported by the imminence of the installation of engine-driven air compressors to provide the motive power for gyros, servo cylinders and other services.

Silencers

In past years most of the work undertaken in connection with exhaust systems has been with a view to reducing fire risk by better cooling and the elimination of local " hot spots " on the exhaust manifolds. Any reduction of noise ensuing has been incidental to this work.

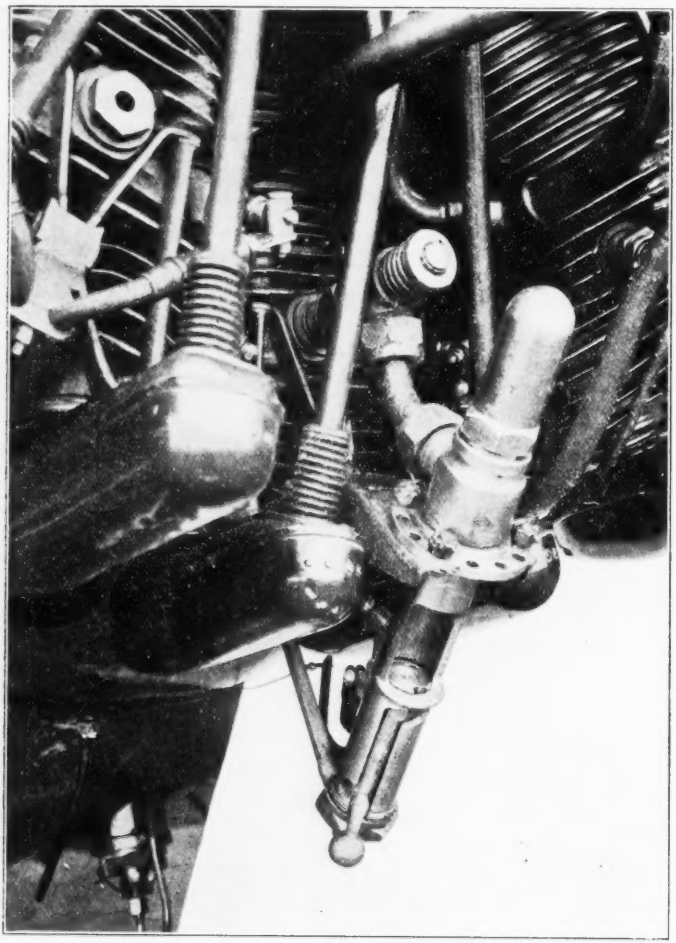

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FIG. 19.

Farman cartridge starter.

The standards aimed at for suitability of exhaust collectors or manifolds, whether silencing devices are included or not, are:—

Maximum back pressure, ½ lb. sq. inch.

Maximum external temperature 300°C.

The latter condition is not generally satisfied.

To allow the occupants of an aircraft to fly for long periods with a minimum of discomfort it is necessary to reduce exhaust noise and also prevent suffering from the inhalation of exhaust gas.

These conditions have been met by leading the exhaust gases to a position in rear of the occupants by means of long tail pipes. At the same time, a noise reduction sufficient to allow wireless intercommunication and flame damping for night operation have been obtained. A reasonable degree of silence is possible also by the use of short perforated pipes with exits below the wings, but with exits below the fuselage the fire risk is increased and the pilot is unable to hear if his engine is firing when gliding in to land.

The following paragraphs describe the types of silencers used on the two chief types of engines.

The perforated long-pipe silencer consists of a light gauge pipe with a closed end, extending from the manifold or collector to the tail of the aircraft, and

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FIG. 20.

Perforated long exhaust pipe on D.H.9A. Puma engine.

was first designed and tested on a " Puma " D.H.9.A. aircraft (Fig. 20). It has been adopted where possible in the Service, and Imperial Airways, Ltd., have also used it on various types of passenger-carrying aircraft. Its design is specially suitable for single water-cooled engined aircraft, and its adoption is due to its durability, simplicity, and flame-damping properties. The exit area of the perforations, usually $\frac{1}{8}$ in. diameter holes, is 130-140 per cent. of that of the open-ended pipe to reduce back pressure to a minimum, requiring some 1,400 holes.

The usual silencer for air-cooled engines takes the form of a collector ring (Fig. 21), designed by the engine builders, to which open-ended tail pipes to suit the aircraft are usually attached.

The volume of the ring collector is some 60 per cent. of the total volume of the cylinders, and has a bearing on the degree of silencing obtained. In the case of the water-cooled engines the volume of the manifold is commonly some 30 per cent. of that of the cylinder block.

The long perforated tail pipe is not easily adapted to multi-engined aircraft with water-cooled engines, as it is not possible to support the requisite length of pipe. The radial engined aircraft has the advantage that long tail pipes are not so necessary, but the improvement obtained on an aircraft with twin " Lion " engines and perforated pipes of a length equal to the chord of the wings was such that intercommunication between front and rear cockpits was possible.

In connection with a general investigation into the reduction of exhaust noise in aircraft, recent tests at R.A.E. of proprietary and other silencers designed for aircraft have shown a reduction in noise of but small degree unless the silencers are constructed of heavy gauge material and surrounded or lined with absorbent heat-resisting lagging, together with an imposed exhaust back pressure on the engine of an inadmissible value.

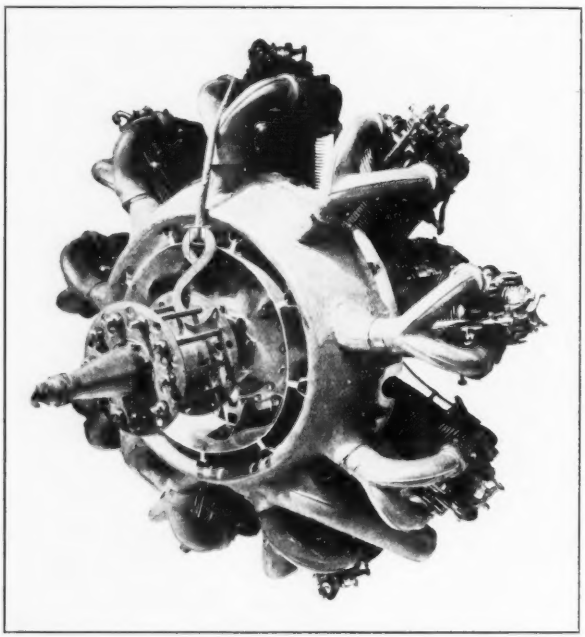

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FIG. 21.

Collector ring on Jupiter.

The intense heat resulting from this combination causes buckling of the metal and rapid disintegration of the lagging. Such a mass at high temperature adds greatly to the risk of fire on crash. Also as comparative tests, with the engine exhaust noise definitely subdued by exhausting through water, and by motoring the engine, indicate that the noises from the mechanical components, exhaust, and airscrew, are of the same intensity, the present position suggests that the reduction of noise necessary for the comfort of the occupants of an aircraft will be more readily and effectively secured by the utilisation of a noise absorbent filling for the cabin walls. This expedient, however, does not provide the quietness required on Service aircraft, whose tactics embrace the advantages of surprise.

Flexible Airscrew Hub

An airscrew hub (Fig. 22), embodying a spring drive and a vibration damper, has been evolved by Major B. C. Carter in the course of torsional vibration investigations at the R.A.E.

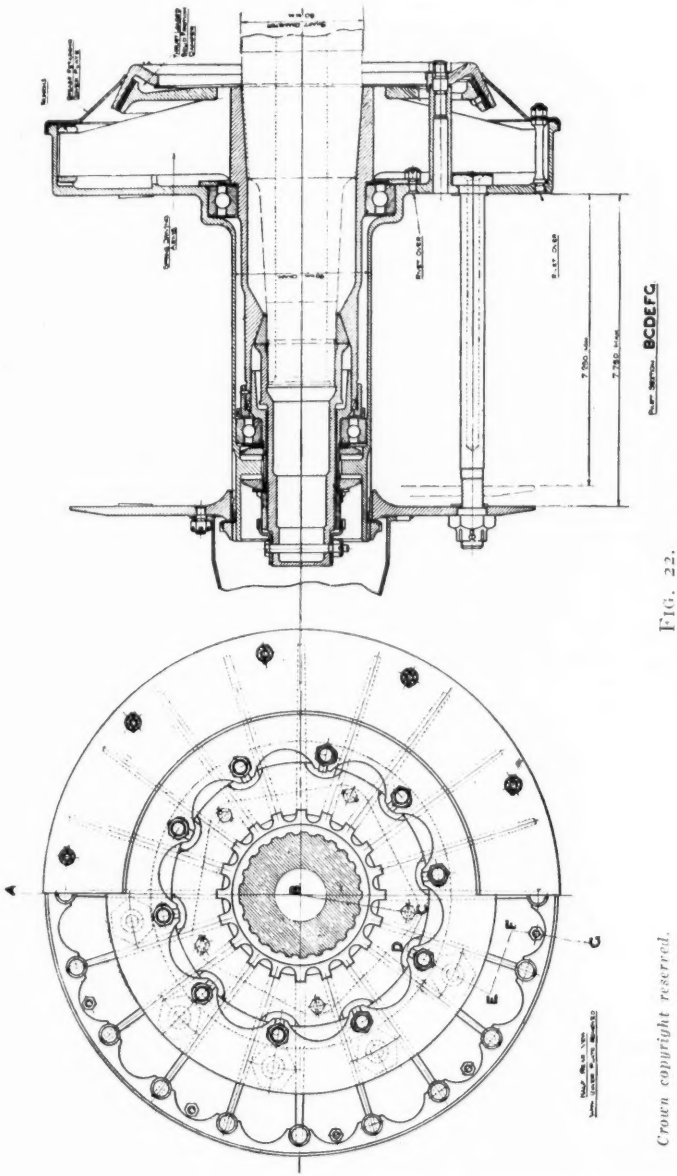

FIG. 22.
Carter flexible airscrew hub.

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The hub is adaptable to wooden, Fairey-Reed, or adjustable pitch metal airscrews, and special designs are arranged for the damping of lateral, as well as torsional, vibration.

The spring element comprises a number of radial arms integral with the splined boss secured to the airscrew shaft, the drive being transmitted through these to the airscrew, which is mounted on bearings to allow a small angular movement relative to the shaft. Trunnion bearings are fitted between the spring blade tips and the driven member.

The spring blades are simple cantilevers, and their design to obtain the desired flexibility and strength presents no difficulties.

The damper comprises two conical rings co-axial with the shaft, so mounted that one rotates with the shaft and the other with the airscrew. The inner ring is faced with bonded asbestos material, and the outer ring is held in contact with it by the airscrew thrust—transmitted to the shaft in this manner. The cone angle and radius of the damper are such that resonant amplification of movement and torque cannot occur.

The hub has undergone hangar and flight tests on " Bristol Jupiter " engines providing satisfactory smooth running and absence of undue wear.

The hub complete weighs 19 lb. more than the corresponding standard hub, but this figure may be discounted by the possible weight saved in other directions by virtue of its properties. The application of the damped spring hub is not limited to engines in which a major critical torsional vibration occurs in or near the operating speed range. Minor criticals occur at fairly close intervals throughout the speed range of all engines, and that these can prove troublesome was exemplified by the engine failures of the Graf Zeppelin. The damped spring hub eliminates these criticals, and its adoption may be justified on this account alone.

Other Accessories

Of the remaining engine accessories, carburettors,[1] oil,[2] petrol and water pumps,[3] oil coolers,[2] filters, flexible pipes, etc., several of these items have been discussed in papers presented before the Society, whilst others, though none the less important from efficiency and reliability points of view, follow conventional types for a given duty, or are proprietary articles, and do not, I think, call for detailed description.

In conclusion, I desire to thank my colleagues at R.A.E., Farnborough, and at Air Ministry, for assistance in the preparation of this paper, and also the aero engine firms for their assistance in supplying representative illustrations.

Discussion

The Chairman: He thought that no one could have listened to Mr. Taylor's lecture without being struck with the ease with which he moved among those multitudinous little levers, and springs, and aneroid capsules, and no less by the extreme complexity of the modern aero engine and the amount of skill and experience and meticulous attention to the details of design which went to the successful building of such an engine. It was the Chairman's fate—or one of his variegated fates—to interview inventors from time to time, and after listening to Mr. Taylor's paper he felt that he would like to have a " talkie " film made of it, and it should be somebody's duty to operate this at the Air Ministry. When an inventor came along with some new engine which was going to supersede all engines hitherto made he would be handed over to the " talkie " film

[1] " Aero Engine Problems in Flight, with Particular Reference to Carburation," November 15th, 1928, R. J. Penn.
[2] " The Lubrication of Aircraft Engines," May 23rd, 1929, F. A. Foord.
[3] " Recent Development in Engine Cooling," March, 1931, A. Swan, R.Ae.S. Journal.

operator and shown that lecture, with its complex illustrations, and with the explanations of how each accessory worked. He would then go away a chastened and a wiser man. One might be tempted to ask whether the designer had not allowed his ingenuity to run away with him—whether there was not almost an excessive complexity about the number of gadgets attendant upon the modern aero engine; but the Chairman thought that the answer to that was that the great aim of such complexity was to produce simplicity in the air. The automatic boost control, the automatic mixture control, the automatic ignition control, produced an appalling apparent complexity on the drawing board, but they all aimed at reducing the control of the engine in the air practically to the movement of the throttle, and the throttle only; in other words, at reducing the number of things on which the pilot's attention had got to be concentrated.

Major F. M. Green (Armstrong-Siddeley): Most of the accessories that the lecturer had mentioned had shown themselves to be necessary and most of them, he thought, would have to be adopted. The most interesting accessories at the moment were two things that were really interconnected—the automatic ignition control and the automatic mixture control. Petrol engines were becoming lighter and lighter and more and more petrol had to be carried; in fact the weight of the petrol was sometimes more than the weight of the engine. It was highly desirable to reduce the amount of petrol that had to be carried. The ordinary carburettor was affected by altitude, and the present means of using a hand-control operated by the pilot was not good enough. The automatic mixture control was becoming a necessity. Connected with this was the use of an automatic ignition control. Contrary to general belief, an engine did not need maximum ignition advance at full throttle, although this may be also maximum engine speed. Ignition did want advancing with the speed, but only to a trifling extent. The ignition does need advancing, however, in order to get the maximum economy with weak mixtures and at part throttle openings. He therefore thought a great deal of time and ingenuity would have to be expended in making a practical device which would give correct mixture control and ignition advance under all conditions of operation. There had been a great number of devices for starting engines, and although comparison was unwise he suggested that, from knowledge of the motor car, compressed air systems of all sorts were unlikely to survive and that, as in cars, electric starting would be the final solution.

Air Commodore Chamier: Speaking of the complexity of the instruments they had seen and the necessity of them, it did strike him that the automatic mixture control, which Major Green picked out, with his vastly greater experience, as being absolutely essential, was the one that he would have felt inclined to leave out. Some things, like boost control, ought, if possible, to be taken out of the pilot's hands, because if they did not receive the necessary attention the machine might be wrecked. He did not know whether there was a fairly simple flow indicator which would give visible indication of the consumption of the engine. They might get the mixture control which they required for long cruising—maximum endurance—by hand operation, and cut out one of those things which everybody was anxious to leave out. The question also arose: What hope was there of cutting out radio interference with coil ignition? Mr. Taylor had told them that if they abandoned the magneto and went to coil ignition that was one of the things which would decide the issue. Those magnetos seemed to have become enormously large and complicated, and apparently very heavy. He would like information on that subject. He felt that electric starters might come into their own. They had electricity for all sorts of things. Why not for starters? Mr. Taylor had said that the objection to the inertia starter was the weight of the battery. When the wireless people allowed them to use the wireless battery for other purposes than wireless, when it could be used for lighting, etc., it might, said the Air Commodore, be only a small addition to

the weight of that battery to put in slightly heavier plates to enable the battery to be used for starting purposes. That would reduce the weight of the electric starter to a considerably more reasonable figure.

Mr. R. K. Pierson (Vickers Aviation Co.): He hoped the automatic boost control mechanism was going to be really reliable, with its capsules, because if it showed any sign of unreliability he could see them having to put on stand-by controls when the automatics got out of order.

Major G. P. Bulman (*Member of Council*): He thought the paper was not only valuable in itself for its clear exposition of detail, as was to be expected from its author, but served both as a monument and a warning—a monument to the achievement of the aircraft engine designer during recent years in producing what was becoming more and more a robot, and a warning that they must see that that robot did not take charge and become a Frankenstein—that all the efforts devoted to increasing the functions of the engine and to make it foolproof did not result in the production of an apparatus which one could hardly hope to make or buy in time of emergency, or, equally important, to maintain in the field. The difficulty was that there were so many different forces operating to make the thing more and more complicated. There was the engine designer himself who, naturally, strove to increase the selling value of the engine and who, therefore, introduced superchargers, self-starters, etc. Then, partly to safeguard his engine for his own sake, and partly in response to a natural desire of the Air Staff to relieve the pilot as far as possible of special duties in running the engine, he added such items as the automatic boost, altitude and ignition controls, quick starting oil devices, thermostats, and so on. Then there were the entirely extraneous requirements of the aircraft constructor and others involving the addition of gun gears, complete ignition screening for wireless, and engine driven generators and air compressors. So many people were driving the same way and it therefore became more than ever essential to insist that anyone conceiving some new idea or new requirement should weigh up the advantages and fully appreciate the disadvantages, so as to be sure that what he was proposing was really worth while.

Major Bulman did not propose to touch on any of the details of the paper since there were probably as many waiting to speak as there were hats downstairs, but he did think it was particularly appropriate in a discussion on engine accessories to devote a moment to underline the reference to the late Major Norman. Although he was mentioned in the paper in connection only with the gas starter, those present whose memory went back ten years and more, would recollect how deeply Major Norman was involved in all aircraft engine development of the time and how great an inspiration he was. Perhaps the greatest tribute one could pay to his memory was to remind them that he was valued and his genius appreciated as much, and perhaps even more, by his colleagues in the industry as within the department, a condition partly due, perhaps, to that magnificent faculty he had for not suffering fools gladly.

Mr. Emtage: He had hoped Mr. Taylor was going to say something about variable pitch airscrews, a subject which was so much wrapped up with that of superchargers, which he had dealt with so adequately.

With regard to automatic boost control, Mr. Taylor had described the two types of operation as illustrated in the Armstrong-Siddeley and the Bristol type of control. He would like to know whether Mr. Taylor had a preference for the oil-operated type, or the other. Did the blow-back tend to upset the capsule, and if so, how did he propose to meet that situation.

As regards automatic mixture control, it occurred to him, while looking at the slide of the control, that it might perhaps very much more conveniently be built into the carburettor, and thus save additional weight and space.

Mr. Emtage was interested to note from the illustrations of the flame trap that the actual corrugations had been designed exactly similar to a flame trap

which had been tried out in 1917. In that case it was a circular flame trap which was placed in the induction pipes.

There was a strong feeling, which had been emphasised by Air Commodore Chamier, that at the present time magnetos were far too heavy. That was brought about partly by screening, which called not only for increased bulk but for a more robust magnetic circuit to give the increased energy. Mr. Taylor had quoted 17¾lbs. for one of the magnetos illustrated as overcoming the effect of the screening. That was not a fair figure in this year of grace. They were in sight of a considerably lighter figure than that, and one was led to hope that before very long the appropriate weight of a magneto for such an engine would be of the order of 12lbs. at the outside. It might be that the introduction of the spring hub described by Mr. Taylor would enable the weight of the magneto to be reduced. At present metal was added purely to withstand engine vibration.

With regard to sparking plugs, the difficulty, he thought, at the present moment was not so much one of dissipating heat as of overcoming fouling. A short time ago one would have said that by using alternative designs of plugs one could cope with large quantities of heat or alternatively with large quantities of oil, so covering all types of engines, but with the increase in the number of supercharged air-cooled radial engines the problem of overcoming fouling had been increased.

The R.A.E. Mark I. gas starter—practically as designed by Major Norman—was still doing very good service, particularly in civil aviation. Gas starting was really a question of getting away very quickly in most cases. If a machine was down in enemy country, possibly under fire, a starter which would get it away by just the pressure of a pedal was probably the most desirable, and that also was the case with civil aircraft which had to start dead on time. One of the problems to-day was whether it was better to go for a continuous turning starter, relying on the hand-starting magneto and priming pump or for some form of high speed flick starter. The cartridge starter was probably the lightest type that one could use. The Farman starter was of the order of 4½lbs. Of course, the ammunition weighed very little. That starter was in regular use at Croydon on certain Continental Air Lines, and could be seen almost daily, but it had the great disadvantage which Mr. Taylor had pointed out, that the engine must be turned into position.

With regard to silencers, the residual noise when anything approaching exhaust silence was obtained could be very distressing. He noticed, living on a main air route and getting a large number of aircraft over, that on the British machines one could hear the gear noise above, and very often before, anything else. One of the biggest problems with exhaust systems had been to find a satisfactory material which would stand up to heat and corrosion. At present the best material appeared to be a soft workable mild steel which was specially treated to resist corrosion.

Flight Lieutenant A. F. Scroggs: He was afraid he had not had personal experience of all the gadgets Mr. Taylor had mentioned, but he believed their development to be very important from the pilot's point of view. A pilot may have many distractions, as when flying low in bad visibility or when attacked by enemy aircraft, and in such circumstances automatic controls may save engine failure.

In his experience, the boost control works well on the whole, but for heavily loaded aircraft an over-riding device is desirable for taking off. He had had nothing to do with automatic mixture controls, but it seemed to him that the question of what mixture is wanted is still too uncertain to make it possible to standardise such an instrument. The same applies to ignition controls and he agreed with Major Green that it should be inter-connected with the throttle and mixture controls, as weak mixtures apparently demand advanced ignition. Con-

trol by r.p.m. only is bad as it leads to retarding when throttled, *i.e.*, just when more advance is needed.

The quick and easy starting of engines is a matter which has not developed as quickly as one would like. The R.A.E. Mk. I. gas starter is a step in the right direction, but it is by no means always effective; the air bottle type is excellent, and he thought the best so far, though inertia starters have given quite good results. It is a relief for the pilot to know that he will not have to get skilled assistance or special apparatus for starting if he lands away from his aerodrome.

There were one or two points on which he would like information. In describing the Watford 8-8 magneto, Mr. Taylor said, if he understood him correctly, that the sparks pass to alternate plugs in opposite directions. Now a spark bridges an unsymmetrical gap (as in an ordinary plug) more easily in one direction than the other, though ionisation by the initial spark may cause subsequent oscillations, and if the conditions are such that ignition is difficult, *e.g.*, with dirty plugs or very weak mixtures, missing might occur on alternate cylinders unless specially designed plugs were used. He would like to know if any sign of this had been noticed, particularly as the economical use of weak mixtures may be restricted by weak sparks. Probably, however, weak mixtures have not been used on the engine in question.

Captain A. SWAN: He thought that Mr. Taylor had advocated many diverse types of starter which were admirable, and one or two seemed very near the ideal. The ideal starter, in Captain Swan's opinion, was a self-contained unit in which only one simple operation, such as pressing a press-cock, was required—the same type of operation as used in cars. It was not always easy to attain that ideal in aircraft because of the limitation in weight and the need for simplicity of installation, also because there were different types of aircraft, some single and others multi-engined types. Of the starters Mr. Taylor had described, those Captain Swan had in mind that seemed to approach the ideal were the R.A.E. Mark II. starter, and perhaps the Farman cartridge starter. In the Mark II. starter the installation was very light. All the pilot had to do was to press the cock; not even engine turning was required. The only drawback—he thought it was a slight drawback—was that the bottle contained only about four starts. The bottle was a very light, thin shell, not what was usually associated in one's mind with a high-pressure air bottle. To make the use of this starter entirely universal it would be necessary really to carry a foot pump or other manually-operated pump, so that innumerable starts would be available. The Farman starter seemed to him a very successful type, and a large number of starts were available, but its drawback was that the whole operation of starting was not performed in the cockpit; someone had to turn the engine until the airscrew was in the right position for the appropriate cylinder to receive the gases from the cartridge. One could see from the paper that there had been a lot of progress in the development of starters. He thought the time could not be very far distant when the really ideal starter would be obtained.

Mr. LOVESEY: He would like to raise the question of flame traps. He did not know whether, when operating at high altitudes, or in humid atmosphere, flame traps were liable to become clogged with snow. It seemed to him that flame traps were one of the things they could leave off for the moment in their struggle against the weight of engines. There did not seem any greater demand for them with the modern engine, using outside air intakes. Mr. Taylor had enumerated several advantages of the inside air intake, but Mr. Lovesey did not think there was much to gain. For instance, with the outside air intake specially arranged considerable advantage could be obtained from the kinetic energy of the air, and so increase the induction pipe pressure. He would like to know if Mr. Taylor had found flame traps give any appreciable advantage in distribution.

It would seem that some of the various automatic controls could be grouped together, as their functions seemed more or less common. For example, he would think that automatic ignition timing and boost control could be grouped together conveniently in one unit and so save duplication of parts.

It seemed to him that it would be an advantage for a boost control to permit maximum throttle opening on the ground level at the discretion of the pilot, for with the possibility that lead-doped fuels would come along in the near future, then extra boost for emergency conditions such as " take-off " from difficult places would be available.

Mr. OWNER: The engine designer, as an individual, had to be rather altruistic in his attitude towards accessories, because so many of them were inflicted on him for other people's benefit. Had the lecturer any information as to developments in connection with gun interrupter gear? Things seemed to have settled pretty well where they had been for many years now, and some development of gun interrupter gear would have to take place. He would welcome information as to what development was proceeding along that line. Mr. Taylor had mentioned another accessory being provided shortly which would presumably have to be carried upon the engine, namely, the air compressor. The services of this air compressor were not specified. If any information could be supplied as to the probable shape, mounting, and horse-power of this unit, it would be of great assistance in finding room for it in an already overcrowded spot. Another accessory of the very near future was connected with screening magnetos. Shielded plugs were now coming into fairly common use in America, and it was fairly certain that radio developments would call for the complete screening of plugs. Had any work been done on the screening of plug terminals? It was said that the cage of supercharger bearings was centred on the balls. That had not been found in Bristol engines to be the most satisfactory method, and the cage was therefore centred on the inner race, not on the balls. Mr. Taylor had mentioned that the exhaust ring volume had considerable effect upon the silence of an engine.

Mr. Owner could confirm that statement from experience. The degree of silence obtained with an experimental exhaust ring of twice the normal volume was extraordinary, as far as the exhaust was concerned; it was such that the airscrew could be distinctly heard above the engine noise.

Mr. C. AMHERST VILLIERS (*communicated*): The paper which has been read by Mr. W. L. Taylor is of great interest as showing his conclusions from the experiments and tests on aero engine accessories that have been made at Farnborough.

The " Roots " displacement type of supercharger has been much improved as regards lightness and smoothness of running at high speeds by the use of special materials and accurate machining.

It can be applied confidently for duties within the range described by Mr. Taylor and has the advantages that he mentions in addition to simplicity. With reference to centrifugal superchargers, as three speeds for the gear reduction have been used in America and other countries, it would be interesting to know whether Mr. Taylor has any experience of these multi-speed types.

As carburettors, starters and other accessories are made successfully by specialist companies, would it not be advantageous to have superchargers also made by subsidiary firms, which would enable these firms to concentrate on the special problems of blowers?

In all the automatic boost and mixture controls described, the regulating means depend on aneroid capsules. The present writer would like to know whether these are reasonably reliable, and to have some details of their material and construction.

With reference to the proposal for one engine throttle control to regulate boost, mixture strength and ignition, it would be interesting if Mr. Taylor could add to his paper drawings of an approved type of installation.

CONTRIBUTION

Prepared by Messrs. R. P. Lansing, C. H. Harill and David Gregg, of the Eclipse Aviation Corporation.

Superchargers

The directly connected supercharger drive is described as apparently being very similar to present developments in America. This is a continuous gear drive, with the usual protection in the gear train to prevent overloading, the impeller being driven at sufficient speeds to give ground performance at 12,000 feet. According to this paper, apparently no ground boost is used and the amount of supercharging is controlled by the use of an automatic boost control.

In such a system there is a considerable loss of power and increase in temperature of the intake, due to throttling below critical altitudes. It would be very interesting to know more of the reasons governing the limitation of supercharger drives to this type as contrasted to other forms, which we understand have been quite thoroughly developed in Europe, in which two or even three stages of gearing are used for furnishing a closer approximation for maintaining the right amount of supercharging, with an open throttle, between ground and rated altitudes, either by manually controlling the different stages of gearing, or even by automatic control. It is understood that with these developments the necessary intercoolers are added after the impellers, for necessary cooling and consequent increase in efficiency.

With the single stage constant mesh type of supercharger there is a distinct limitation of the amount of supercharging that can be used, with the very obvious disadvantage of inefficiency on the ground and it would be very interesting to know more of the relative merits of the two types mentioned above, development of which has apparently been in favour of the single stage type.

With regard to the positive type supercharger, apparently the reasons for its lack of use in military aeroplanes is due to the bulk more than to the weight, if the superchargers are available in the efficiencies and weights, as given by the author in his paper, for engines of 465 horse-power. It has been apparent that for high speed aeroplanes, such as the pursuit type, which are designed around the radial air-cooled engine, the whole design of the aeroplane would be radically disturbed by the need for increased length behind the engine to adapt the Roots type of supercharger. Apparently this fact alone has brought about the use of the centrifugal as against the positive type.

Battery Ignition

The question of battery ignition *vs.* magneto ignition seems to be one of those things which follows in cycles. Ten or fifteen years ago a great many of the aircraft engines flying in this country were equipped with battery ignition and this type of ignition was accepted at that time as relatively quite satisfactory. With the further development of the aircraft engine, particularly toward reliability, improved magnetos, both as to reliability and weight, and long life, came into being until practically all engines now flying are equipped with magneto ignition. On the other hand there is at the present time a very strong feeing that battery ignition is being given a great deal of thought, not only by manufacturers of equipment, but particularly by operators. One of the logical underlying reasons for the return of battery ignition is the development of complete electrical systems and the fact that the electrical supply is being depended upon more and more for different uses. Among the first were the requirements for lighting, cloth heating, and signal appliances. In more recent years the use of radio has gradually increased until at the present time it is in more general use than most people had contemplated. The fact that the battery

is the essential requirement for all of these purposes is sufficient assurance that electric starting is the most efficient, practical and effective type of starting. While it is true that the electrical equipment is found in greater use the larger the class of aeroplane started, electrical systems have made intrusions all down the line to the very smallest types and, in view of this fact, with the electrical system as a fundamental requirement, the change from magneto ignition to battery ignition is but a natural step and will result in a very definite saving in weight. It is, therefore, natural to expect in the not far distant future to see battery ignition come more and more into use on electrically-equipped aeroplanes.

Starters

With regard to starters, the inertia starter is by far the most popular type of starter used in this country, except on the smallest aeroplanes. The inherent advantage of the inertia starter over the other types is an advantage which is very apparent and has been very well proven over the last seven years. This advantage is the comparatively high momentary cranking speed which is made available, particularly on the larger engines, without taking a correspondingly large current consumption from the electric battery. This high speed of cranking is, of course, available just as well from the hand form of inertia starter, without the use of any battery or without the energy supply other than man power. In the electric inertia starter the amount of energy used to accelerate the starter is always a constant, depending upon the inherent characteristics of the starter. The condition of the engine to be started, namely its stiffness and its temperature, has no bearing on the amount of current consumption as in the usual form of electric starter. The advantage not only lies in the output obtainable from such a starter but is much less abusive on the storage battery and for that reason smaller and lighter batteries can be used very effectively. In the smaller engines, namely under 200 horse power, while the inertia starter still gives the same advantages, the direct cranking electric starter has the advantage of low cost and lighter weight and, with the more efficient form of gearing now in use, the direct cranking electric starter has been found to be very satisfactory.

With regard to the use of inertia starters on the wing-engined aeroplanes, there is a development known as the External Power Unit which consists of an electrical motor, together with the necessary additional mechanical development to enable an operator to use a power supply line from the hangar for the purpose of accelerating the inertia starter, in either the hand or the combination hand and electric form. On many of our airlines in this country this equipment is in quite general use and the advantages of the inertia starter are enjoyed without necessarily depending on either the battery or the difficulty in getting at these winged engines in view of their height, from the ground, with the manual hand crank. We would like to emphasise, however, that, as mentioned above, a great many of these transport planes in daily use are using the electric inertia starter and in one particular case, where small engines are used, the direct cranking electric starter is used, and thousands of starts are made per day without the system in general being given any greater amount of attention than any other part of the aeroplane. In other words, the electric starter, more generally in the electric inertia form, has become an approved, satisfactory prerequisite to scheduled transport operations.

Propellers

The flexible propeller drive described, consisting of a torsional spring and friction cones for dampening out torsional vibrations of the engine crankshaft as transmitted to and from the propeller, is desirable only if the additional weight involved warrants it. This is as applied to present conventional types of engines, —the Diesel excepted. The assumpton that the weight of the torsional dampener

can be regained by making lighter weight blades or lighter crankshaft has not been borne out in practice, as blades should be strong enough to withstand the various types of vibration which act in various ways with innumerable secondary periods of vibration. In addition to the above vibrations, there sometimes occur vibrations due to "out of track" or "blades not of the same pitch." As it is imperative that propellers should not fail under any operating type of vibration, the weight of the vibration dampener must be looked upon as purely additional.

Reply to Discussion

The reasons for the increase in number of engine accessories had been clearly stated by the Chairman and Major Bulman, and the adoption of most of them agreed to by Major Green.

The practice of forcibly feeding an aero engine at altitude necessitated the introduction of the boost control for its protection against over-feeding, and later, the same control had been modified to regulate the quality of the food under all operating conditions. He agreed that a device to automatically control ignition advance in correct relationship with the mixture strength obtaining over the throttle range, was very desirable, and thought that another adaptation of the servo control would meet the case. One advantage of maintaining the same principle of operation for these automatons was that the perfection of the component parts of one unit led to the perfection of the others, and their functions and maintenance requirements would be more easily understood.

Depending on its severity, a blow back will upset the capsules. They can be protected by choking the pressure pipe connected to the housing and by the installation of flame traps. As far as he knew, equal satisfaction was being obtained from both oil- and air-operated types and he had not at the moment a preference for either. The capsules did not require readjustment for long periods and their reliability had improved with added manufacturing experience. The capsules were similar to those used in recording altimeters and were proprietary articles obtainable from approved instrument makers.

In connection with Flight Lieut. Scroggs' contention that the power jet should be operated by the boost control instead of the throttle, he would point out that, in essence, this is done. In the R.A.E. type, for full take-off power, the throttle is moved through the gate to full open position to adjust the boost control to maximum permissible boost and the power jet is linked to the throttle in this position. The throttle controls both units.

Regarding Mr. Lovesey's advocacy of the advantage of a boost control to permit maximum throttle opening at the discretion of the pilot, it seemed to the lecturer that this entirely negatived the function of a boost control. He could not understand the necessity for the provision of a means to protect the engine and at the same time permit the pilot to over-ride it at his discretion.

In reply to Mr. Lovesey, a flame trap does not promote freezing, but if frozen deposits are present in the induction system, a flame trap will partially clog. To prevent this, the correct position for a flame trap is on the cylinder block with a metal-to-metal joint for the trap housing. If air intakes inside the cowling are used, he did not think clogging was possible. Any improvement in distribution due to fitting flame traps depended on the type of engine.

The kinetic energy of the air with special outside engine intakes was only of potential value at high aircraft speeds (1.1/3 per cent. increase at 200 m.p.h.) not during climbing or fighting when all the conditions for good carburation and distribution were necessary. Except in special racing machines he would not forego the advantages to be obtained from flame traps and internal intakes.

In reply to Mr. Emtage, variable pitch airscrews would considerably better the rate of climb from the ground of supercharged engines but the supercharger systems suitable would be the exhaust turbo centrifugal compressor with exhaust

manifold gates, or a displacement blower with bye-pass valves before the pressure carburettor. The extra blower power absorbed and the temperature stress imposed on the engine would oppose its use with a direct gear-driven centrifugal blower.

In reply to Mr. C. Amherst Villiers, the lecturer has, to date, no practical experience of multi-speed blower drives. Their employment will ease slightly the induction temperatures and may prevent engine failure from excessive temperature on climb, but so long as fixed pitch airscrews are used their influence on power will be slight. He thought the engine manufacturers could best answer the suggestion to have subsidiary firms make the blowers as, in radial engines, these are "built-in." He feels that one engine throttle control to "regulate boost, mixture strength, and ignition" is a misunderstanding. He, the lecturer, contends one throttle control only for the pilot to control the engine; automatics to control, unaided by him, the other functions.

Air Commodore Chamier had asked whether there was a simple visible indicator of engine fuel consumption. A fuel indicator for mass flow, accurate to 1 per cent., is available, but there is not an indicator to show the pilot that the engine is operating with the desired economical fuel consumption. To obtain the desired mixture strength on long cruises, he understood the general opinion to be that a mechanically controlled device would afford superior results to manual operation. The Air Commodore had also inquired about the possibility of subduing radio interference if coil ignition were substituted for the apparently heavy present-day magnetos. He was not an expert on radial telephony; he understood that disturbances in the R/T apparatus would be more severe with coil than with magneto ignition. The passage of the spark at the plug on the H/T side is associated with a similar transient sudden rise of potential in the L/T side and gives shock excitation to the whole of the primary system, leads, etc. These transients are picked up and magnified in the W/T apparatus. Their effect can be lessened by filter circuits, but additional weight is incurred. To date, a practicable scheme of screening and filtered circuits for coil ignition apparatus had not been obtained. At present he was against the utilisation of coil ignition or in fact any electrical accessory which necessitated the low tension electrical leads being brought forward of the fireproof bulkhead, on account of increased fire risk on crash. He recollected the many fires on crash with coil ignition on Liberty 9A.'s, and though American tests purported to show that fire resulted from the exhaust manifolds, he was not convinced that the shortening of the L/T leads was not equally responsible. Crash-proof switches might be a solution, but their efficiency depended on the type of crash.

Regarding electrical starters, his experience was rather out of date, limited, and not encouraging from the point of view of weight and the number of starts possible on one charge of the battery. With one proprietary system weighing 70lb., only one to six starts per battery charge were obtained.

A 50 per cent. increase in the starter reduction gear ratio to 150:1 and heavier accumulators giving a total starter system weight of 90lb. afforded satisfactory starting at normal air temperatures. Low air temperatures greatly increased the load on the battery and seriously reduced its service per charge. If a large general purpose battery were installed it was likely that a separate battery for the filament lighting of the wireless apparatus would be insisted upon. He did not think that electric starting would be entirely suitable on compression ignition engines. Should a compression ignition engine stop, during gliding in to land, he thought a compressed air starter was the only type which would give the required immediate restart.

In reply to Mr. Owner, shields for screening of plug terminals have been in use in the Service on certain engines for special duty for some ten years. He could not dispute Mr. Owner's point that his firm had found it better not to

centre the cage on the balls of a ball-bearing since the experience accumulated by his firm during recent production of engines was bound to be more conclusive than that obtained from limited laboratory tests.

In connection with Major Bulman's tribute to the late Major Norman, he was glad to join Major Bulman in an expression of the great esteem in which Major Norman was held, by his colleagues and himself.

Reply to American Contribution

In reply to the contributions to the discussion from Messrs. R. P. Lancing, C. H. Havill and David Gregg, of the Eclipse Aviation Corporation, Mr. Taylor would refer them to the remarks of Messrs. C. Amherst Villiers and Mr. Emtage and his replies thereto in connection with supercharger drives.

The author appreciates the views and statements expressing the present position of battery ignition and starters in U.S.A. contributed by these gentlemen, and though not in entire agreement, as his replies to other contributions show, is aware that similar views are widely held in this country, and it is likely that many installations as described will be carried out here in the future.

In connection with their remarks regarding the flexible airscrew drive, he does not agree that the extra weight of the hub and damper cannot be offset at all by saving in other directions, but agrees that the extent to which it can be offset, depends upon the engine design concerned.

Several engines, now obsolete, having died of torsional vibration were increased in weight and/or reduced in rating in vain attempts to overcome the trouble whilst airscrews and hubs satisfactory on other engines required to be made heavier also. It cannot be argued that airscrews which are able to withstand gyroscopic forces and non-torsional vibrations are able to withstand severe torsional resonance. The damped spring hub may be regarded as a device which can be used when necessity arises, though the necessity is not so liable to arise now that the knowledge of torsional vibration has become more widely known. Engine designers would have more freedom, however, if they could disregard torsional periods and reckon upon using a damped spring hub preferably available as part of the airscrew.

AN ENGINEER'S CONCEPTION OF MATTER AND ITS APPLICATION TO MATERIALS OF CONSTRUCTION

BY

E. W. STEDMAN, M.I.C.E., M.E.I.C., F.R.AE.S., A.R.C.SC., ETC.

I.—INTRODUCTION

Most engineers have a sound working knowledge of the handling of materials of different kinds, and of their properties, and make use of these well-known properties. If, however, the engineer attempts to explain any of these properties he frequently finds that his training has not equipped him with an acceptable explanation.

In recent years much work has been done towards explaining these properties, but this work is dealt with in the specialist works of chemists, physicists and metallurgists, and is usually not easily available for the engineer, involving as it does a great deal of reading and investigation.

The types of questions referred to are:—

(1) Duralumin if heated to about 500°C. and quenched is soft, but with melting point of the second metal, but may be higher. Why?

(2) Pure copper is an excellent electrical conductor, but its resistance is greatly increased by the addition of a small quantity of impurities. Why?

(3) If a small quantity of one metal is added to a second metal, the melting point of the alloy so formed is usually lower than the melting point of the second metal, but may be higher. Why?

In preparing this memorandum the object has been to give by easy stages a theoretical explanation of as many phenomena as possible. At each step it is realised that many alternative explanations can be put forward by the specialists. These alternatives have been purposely avoided in order to avoid confusion.

The author appreciates that he will be accused of inaccuracy or misstatement, but if the memorandum gives to those engineers who have not the time or opportunity to study the books referred to, a working idea of the trend of modern investigations, its purpose will have been achieved.

For the reader who wishes to pursue the subject further, the two books, "Introduction to Physical Chemistry," Maass and Steacie, "The Science of Metals," Jeffries and Archer, which have been largely consulted and quoted, are strongly recommended.

The author wishes to express his appreciation of the assistance and kindly criticism given by Prof. Sproule, of McGill University, and Dr. Boyle and his associates of the National Research Council, Ottawa.

II.—THE ATOM

(References:—"Modern Scientific Ideas," by Sir Oliver Lodge; "X-ray Past and Present," by Pullin and Wiltshire; "Metals and Metallic Compounds," Vol. I., by Evans; "Science of Metals," by Jeffries and Archer; "Introduction to Contemporary Physics," by Darrow.)

The *atom* is wholly composed of electricity. It is a grouping of electrons and protons and consists of nothing else. A proton is much heavier than an electron (1,850 times) and carries a positive charge of electricity, the electron

carrying a negative charge of electricity. The atom can be considered as a heavy centre or nucleus surrounded by what might be called a miniature solar system of electrons.

The nucleus consists of a number of protons interleaved with a number of electrons, but as there are fewer electrons than protons the nucleus as a whole is positively charged. The number of excess protons in the nucleus is equalled by the number of planetary electrons outside the nucleus.

It is essential to obtain an idea of the small size of the atoms and of the electric charge carried by the electrons and protons; 250,000,000 atoms in a row would be about an inch; 100,000 electrons in a row would stretch something like an atom. It is also necessary to appreciate that the atom is mainly space. If the atom were magnified to the size of a cathedral each component electron would be something like the size of a gnat. The mass of an electron is about 9×10^{-28} grams, and its electrostatic charge is 4.77×10^{-10} electrostatic units.

At this stage it might seem desirable to indicate by a sketch the construction of an atom, but it seems to be impossible to represent the atom due to its dynamic rather than the static nature.

It is known, however, that the central nucleus is surrounded by a collection of orbits, in each of which an electron is or may be revolving. These orbits may be circular or eccentric elliptical orbits reaching out to quite a distance from the nucleus.

The elements can be considered as being made up of various kinds of atoms differing only in so far as the number of electrons and protons is concerned. Some reserve must, however, be made upon the character of a nucleus in the hydrogen atom. The atom is, therefore, the smallest possible unit of an element, and excepting the atoms of the so-called radio-active elements it is extraordinarily stable, passing from one state to another, or combining with other elements, but always retaining its identity as the atom of an element.

Starting at the lighter elements, omitting hydrogen, the first is helium, which is known to be inert. It does not like combining with other elements. The helium atom is found to contain a nucleus with two electrons circulating around it. From the known properties of helium it is deduced that this system consisting of the nucleus with two electrons is very stable.

The next element is lithium which has a nucleus and three planetary electrons. It is known that the helium atom with two electrons is inert. Therefore, it can be expected that the lithium atom would have one electron too many to be itself inert. This is exactly borne out by the action of a lithium, which always tends to combine its one extra electron with another system.

Other elements follow lithium, but it is better at this stage to consider another type of element, *i.e.*, the element which is short of its supply of electrons. Fluorine is an example. This element has a nucleus and nine planetary electrons. It is known that two electrons form an inert body, and it is found that if the system has an additional system of eight electrons as in neon the result is another inert body. Therefore, fluorine having only nine planetary electrons is short by one electron of becoming inert. Fluorine can, therefore, be regarded as seeking continually that extra electron. Sodium like lithium has one excess electron, having a nucleus and eleven planetary electrons.

Sodium having eleven planetary electrons, the system can be assumed to be built up of inner orbits carrying two electrons, followed by larger orbits carrying eight electrons, finally one solitary electron in a still larger orbit.

The fluorine atom can be considered as consisting of the nucleus with two electrons in the inner orbits followed by seven electrons in the next system of orbits. This would be a closed and inert system if it were not for the lacking electron. It can, therefore, be predicted that the sodium atom and the fluorine atom will combine to form a compound NaFl, in which the extra electron of the sodium atom fits into vacant space in the fluorine atom. It will be seen later

when considering electrical conductivity that this compound could also be predicted to be a non-conductor, because in the crystalline state it has no excess electrons. Actually NaFl is a crystalline solid, which is a non-conductor and has a high melting point.

It has been seen that starting with the inert gas helium and adding electrons a series of elements is built up which finally again become inert when a total of ten electrons is reached, which form a closed system and exists as the inert gas neon. Starting from neon and adding electrons another series of elements is built up which finishes with a total of 18 electrons arranged as (2, 8, 8) in the inert gas argon. Similarly starting from argon and adding electrons a long series of elements is built up ending with 36 electrons arranged (2, 8, 8, 18) in the inert gas krypton.

Similarly starting from krypton and adding electrons another long series of elements is built up ending with a substance with the electrons arranged (2, 8, 8, 18, 18, 32) which is niton, the first product of disintegration of radium. Similarly, starting from niton and adding electrons the elements of the radium thorium and uranium series are built up. This series is not complete, and is composed entirely of elements which are continually decomposing.

By arranging the elements in the manner indicated the " periodic table " (Fig. 1) of the chemists is produced. Those elements having no free electrons are the inert gases. Those elements having one excess electron form the potassium group. Those elements having two excess electrons form the calcium group. Those elements lacking one electron form the chlorine group, and those lacking three electrons form the nitrogen group. A typical abridged periodic table is shown in the attached figure.

It will be found that by regarding elements in the manner indicated, a good understanding can be obtained for the reasons why certain elements of vastly different atomic weights have similar properties.

It is particularly interesting to find that other properties such as melting points, coefficients of thermal expansion, etc., vary periodically in accordance with the grouping found in the periodic table.

The atomic weights of the elements increase continuously through the periodic table, with the exception of some pairs of elements such as " argon " and " potassium," in which the element with the greater atomic weight is placed before the other. The positions given to these elements can, however, be checked by the curious fact that the square root of the frequency of any particular X-ray line obtained with different elements, follows a straight line law, without any periodic variation as found for other physical properties.

The various properties of the elements can be considered as being related as follows:—

(*a*) Radio-activity and mass as related to the nucleus.
(*b*) X-ray spectra to the inner electrons.
(*c*) Periodic properties such as valency and optical spectra to the outer electrons.

III.—Gases, Liquids and Solids

(References:—" Introduction to Physical Chemistry," by Maass and Steacie; "Metallography," by Tammann, translation by Dean and Swenson.)

Gases

A useful way of regarding a gas is as follows:—

It is assumed to be composed of molecules. The molecule can be regarded as a collection of atoms arranged in the manner previously described, that is, if the gas is an inert element the molecules are single atoms; otherwise the molecules consist of two similar atoms such as O_2, N_2, etc., or the requisite number of

PERIODIC TABLE.

0	IA.	IIA.	IIIA.	IVA.	VA.	VIA.	VIIA.	Transition Elements.			IB.	IIB.	IIIB.	IVB.	VB.	VIB.	VIIB.	0
2	3	4	5	—	—	—	—	—	—	—	—	—	—	6	7	8	9	10
He	Li	Be	B	—	—	—	—	—	—	—	—	—	—	C	N	O	F	Ne
10	11	12	13	—	—	—	—	—	—	—	—	—	—	14	15	16	17	18
Ne	Na	Mg	Al	—	—	—	—	—	—	—	—	—	—	Si	P	S	Cl	A
18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
A	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
Kr	Rb	Sr	Y	Zr	Nb	Mo	—	Ru	Rh	Pd	Aq	Cl	In	Sn	Sb	Te	I	Xe
54	55	56	57	58	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Xe	Cs	Ba	La	Ce	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	57-71 Rare earth metals.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	73	74	75	76	77	78	79	80	81	82	83	84	85	86
—	—	—	—	—	Ta	W	—	Os	Ir	Pt	Au	Hq	Tl	Pb	Bi	Po	—	Nt
86	87	88	89	90	91	92	—	—	—	—	—	—	—	—	—	—	—	—
Nt	—	Ba	Ae	Th	VX_2	V	—	—	—	—	—	—	—	—	—	—	—	—
	Potassium group...	Calcium group...													Nitrogen group...		Chlorine group...	

FIG. 1.

atoms of dissimilar elements to form a stable molecule as H_2O, CH_4, etc. It is also of assistance to think of the molecule as behaving like a perfectly elastic sphere.

The molecules themselves are in continual motion in all directions and obey Newton's Laws of Motion. The pressure which the gas exerts on the walls of the containing vessel is due to the hits recorded by its moving molecules. The temperature of a gas is a measure of the kinetic energy of the molecules.

Boyle's Law

If the *temperature* of the gas is kept constant and the volume is decreased, the number of molecules per unit volume is increased, and the number of impacts in unit time is increased. The pressure is, therefore, increased. If the *volume* is kept constant and the temperature is increased, the average energy or velocity of the molecules is increased, and the force with which they strike the wall, *i.e.*, the pressure is increased. If the *pressure* is kept constant and the temperature is increased, the average velocity of the molecules is increased and, therefore, fewer hits are necessary to maintain the same pressure. In order to satisfy this condition the volume must increase.

We know that Boyle's law only applies to an ideal gas, and at low pressures, because it has been assumed that the molecules themselves have a negligible volume, and that they have no influence on one another. The changes due to these additional factors can be made and result in Van der Waal's equation.

Van der Waal's Equation

If the molecules have a finite volume then the space available for molecular motion is not the volume of the container V, but is the free space $(V-b)$ where b is the volume of the molecules themselves. As the pressure increases, or as the temperature decreases, the volume of the molecules becomes greater and greater compared with the free space available for molecular motion. Consequently the error due to neglecting the volume of the molecules becomes greater as the pressure is increased, or the temperature is decreased.

A molecule colliding with a manometer for measuring pressure is necessarily on the surface of the gas body. It is, therefore, subjected to a resultant inward force due to the lack of attraction of gas molecules on the wall side, and consequently on moving upwards towards the manometer it must have its velocity diminished.

The pressure recorded on the manometer is, therefore, due to the impacts of molecules with a kinetic energy less than the average kinetic energy of all the molecules in the gas. It follows that the actual pressure due to molecular movement in the body of the gas is greater than that recorded on the manometer. The value of P used in the ideal gas law must, therefore, be increased by an amount to account for this difference in pressure, and this extra amount can be assumed to be approximately equal to a/V^2 where "a" is a constant. The gas equation can, therefore, be written $(P+a/V^2)(V-b)=C$. This is called Van der Waal's equation. When the pressures are very low V is large, and a/V^2 and b becomes negligible, the gas then obeys the ideal gas law.

Gases at High Pressures

When gases are subjected to high pressures the molecules are brought very close to one another so that the volume of the molecule and the laws of force governing molecular attraction may be altered. These effects are of small importance up to pressures of say 50 to 100 atmospheres, but eventually they make themselves felt and Van der Waal's equation does not hold.

We also know that by increasing the pressure and decreasing the temperature all gases can be liquefied. There is, however, a critical temperature above which increase in pressure does not cause liquefaction, but instead there remains

a dense gas which would expand on release of the pressure. There is so little difference between the gas and the liquid in the neighbourhood of the critical temperature that experiments to determine this temperature depend upon the recognition of the meniscus separating the gas and the liquid in order to determine when liquid begins to form.

The Liquid State

As it is possible for substances to pass from the gaseous to the liquid state and vice versa without any abrupt changes in properties, it follows that there cannot be any very great difference between a liquid and a gas at high pressure. The liquid is very much denser than a gas at atmospheric pressure, yet it is composed of the same sort of molecules from which it follows that in the liquid these molecules must be much closer together.

This proximity of the molecules has an important bearing on the factors which caused the departure from the ideal gas laws, namely, the volume of the molecules and their attraction for one another. In fact the molecular attraction has reached such a large value in the case of liquids that the forces between the molecules tending to hold them together are sufficiently strong to overcome the repulsion between them, due to the kinetic energy or " bounce," and the liquid does not tend to expand as did the gas. The molecules are, therefore, no longer able to escape from one another and liquids thus have a definite volume.

Surface Tension

As a liquid has a definite volume it can be contained in a hollow vessel with a free surface. Molecules situated in the mass of the liquid, therefore, will be subjected to attractive forces equal in all directions, and will move about and possess kinetic energy just as a gas molecule does. This is not true, however, for a molecule at the surface of the liquid where there are more molecules within its sphere of attraction below it than there are above it. Its motion parallel to the surface will not be affected, but its motion upwards will be diminished and its motion downwards increased. All the molecules in the surface of the liquid are, therefore, under a downward force due to molecular attraction. This downward force at the surface gives rise to the property of the liquid known as " surface tension," due to the molecules trying to squeeze themselves into the liquid.

Vapour Pressure—Latent Heat of Evaporation

We know that a liquid exists in equilibrium with its vapour, and this condition can be explained by the same sort of reasoning. The molecules in the liquid move about with average velocity, depending on temperature. The condition which prevents the escape of a molecule moving in a direction perpendicular to the surface is that its kinetic energy is less than the work which must be done in order to pull it out of the region of attractive forces. At any temperature the molecules have a certain average velocity, but there will always be a certain number of molecules which have higher velocities, sufficient to allow them to escape. If the liquid and its vapour occupy a closed vessel, any molecule which escapes from the liquid increases the pressure of the vapour in the space above the liquid. This will result in an increased number of molecules finding their way back again into the liquid, so that eventually for a given temperature an equilibrium pressure will be reached when the number of molecules leaving the liquid is equal to the number returning to it. This definite pressure is known as the " vapour pressure."

If the vapour molecules instead of being confined are allowed to escape, more molecules will leave the surface of the liquid carrying energy away with them and, therefore, the temperature of the liquid will be lowered. The heat required to replace this cooling effect is called the " latent heat of evaporation."

The Solid State—Latent Heat of Solidification—Freezing Point—Raising of Freezing Point by Pressure

When a liquid is cooled contraction occurs due to the increased predominance of molecular attraction as the kinetic energy of the molecules decreases. A temperature must, therefore, be reached where the free motion of the molecule in all directions ceases. This is a definite temperature for every substance, and is known as the " freezing point."

Consider two neighbouring molecules in the body of a liquid. Suppose that on cooling the liquid these molecules are brought together by its contraction, and take up the position in which their forces of attraction for one another are most pronounced. If now the energy which they possessed due to relative motion and rotation is subtracted they will be left in a permanent fixed position relative to one another. The " latent heat of solidification " is the heat which must be extracted at constant temperature in order to bring about this solidification.

The sharply defined freezing temperature is due to the fact that there is a definite degree of proximity necessary to cause the adhesion of the neighbouring molecules. The position assumed by the molecules is that of definite maximum attractive force, and other molecules add themselves to the nucleus thus formed in a definitely arranged manner. This arrangement is manifested by the crystalline form of the substance.

The molecules have now lost their freedom of motion and rotation, but they are left with the energy due to the vibration of the atoms relative to one another. The identity of the *molecule* is now lost, and the solid can best be regarded as being composed of *atoms* arranged in a definite and orderly manner. It should be pointed out that all solid substances are crystalline, but some substances having the appearance of solids may be very viscous liquids.

Increase in pressure increases the temperature at which a metal becomes solid on cooling, or becomes liquid on heating. This is due to the fact that the higher pressure causes the atoms to approach one another sufficiently closely for solidification at a higher temperature than would be the case under normal pressures. Bismuth and antimony are exceptions, having lower melting points at higher pressures. Most metals expand on melting, but bismuth and antimony contract on melting.

These phenomena can be more easily understood by considering the equilibrium diagram for an ideal substance, showing the variation in state with temperature and pressure (Fig. 2).

The curve ABC represents the boundary between the vapour and solid and liquid, and the curve BDE represents the boundary between the liquid and solid.

For molten metals at atmospheric pressure the condition is represented by the point F. Any increase in temperature necessitates an increase in pressure in order to produce solidification. At a point D there is a maximum temperature for solidification. For increased pressures beyond this point it is necessary to reduce the temperature in order to produce solidification.

At the point D there is no change in volume in solidification; for higher pressures there is an increase in volume, and for lower pressures there is a decrease in volume on solidification. Bismuth falls in the region DE at atmospheric pressure.

At some point such as E there is a maximum pressure beyond which solid metal cannot be obtained. This point E corresponds with the point of no latent heat of solidification.

With metals, the changes in melting point produced by any pressure likely to be met in practice are so small as to be negligible.

Under conditions usually met in nature increase in pressure lowers the freezing temperature of water. This has important applications in such things as the movement of glaciers, in skating, etc. At very high pressures, however,

increase in pressure raises the temperature of the freezing point again. These anomalies are due to allotropic changes which occur under different conditions.

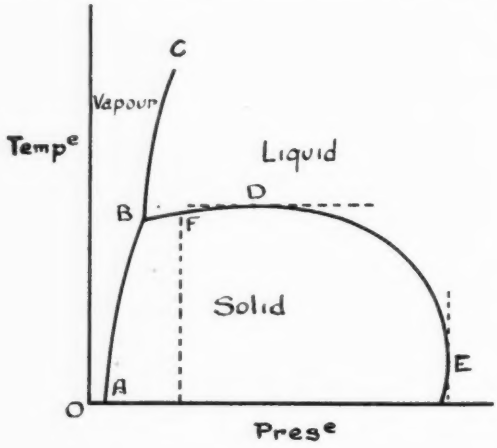


Fig. 2

IV.—The Crystalline Structure of Metals

(References:—" Science of Metals," by Jeffries and Archer; " X-rays Past and Present," by Pullin and Wiltshire; " X-rays and Crystal Structure," by Bragg and Bragg.)

The application of X-ray analysis has enabled the crystal structure of substances to be investigated and measured. In the molten condition the molecules are arranged in a haphazard manner, but when the substance crystallises it has been seen that the molecules group themselves according to definite and repeating patterns.

Space Lattice—Cleavage Planes—Slip Planes

The pattern which forms the foundation upon which the crystal is built is known as a " space lattice." Space may be imagined as divided into cells by three sets of parallel planes. The planes in each set are at equal distances from each other, but the distance between planes may be different in the different systems, and the three sets of planes may form any angles with each other.

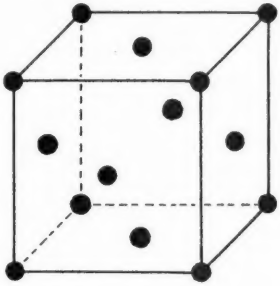
When a crystal is allowed free development it assumes a form bounded by plane faces which are determined by the lattice of the crystal. The so-called " cleavage planes " and " slip planes " in crystals are determined also by the space lattice, being the planes upon which there are the greatest concentrations of atoms.

Crystal Systems

Six main types of crystal structures have been recognised, but for the present purpose it is only necessary to consider the cubic system to which most metals belong. In this system three sets of parallel planes are all equally spaced and at right angles to one another.

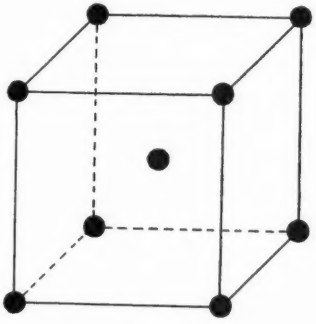
Two arrangements of atoms on this type of lattice are common among metals. The most common arrangement is called the " face-centred cubic arrangement " in which the atoms are placed at the corners of a cube and also at the centre of each face, Fig. 3. This constitutes the closest possible packing for a number of

equal balls, and is sometimes referred to as the " cubic close-packed arrangement." The next most common arrangement has an atom at each corner of the cube and one at the centre. This is called the "body-centred cubic arrangement," Fig. 4 and is not so closely packed as the face-centred cubic arrangement. Therefore, if a metal changed from a face-centred arrangement to a body-centred arrangement there would be an expansion due to the greater distance between the atoms.



Face Centred Cubic Arrgt.
FIG 3

It is important to keep in mind that if two metals crystallise in the same kind of lattice, the size of the unit cell will be different for each metal. This difference accounts for the distortion of the lattice which occurs in solid solutions, as referred to later.



Body Centred Cubic Arrgt.
FIG. 4

Interatomic Forces

In order to obtain a clear understanding of the physical properties of metals, it is necessary to visualise the magnitude of the interatomic forces. If a piece of metal is subjected on all sides to hydraulic pressure the whole of the structure is subjected to compression forces tending to make the atoms approach one another, and it is well known that these forces must be exceedingly great in order to produce any appreciable shrinkage of the metal.

The forces between atoms which resist separation are very difficult to imagine because of the lack of anything approaching a negative hydraulic pressure. In an

ordinary tensile test the specimen is subjected to tension in one direction and a secondary compression in directions at right angles.

Some idea of the forces, however, can be obtained by measuring the tensile strength of very fine fibres, and from this work it has been estimated that the force required to separate atoms of glass would be of the order of 1,600,000 lbs. per sq. inch. Also an estimate based upon the energy required to separate the atoms of metals by vaporisation gives a value of about 5,000,000 lbs. per sq. inch. This is only a rough estimation, but it is sufficient to indicate that in thinking of metals we should not wonder why metals are so strong, but rather we should enquire why metals are so weak. Incidentally this figure shows the enormous possibilities for improving metals.

Thermal Conductivity of Metals

It has been seen that a metal is composed of atoms arranged regularly under the action of their mutual forces, and continually vibrating about their mean positions. It has also been seen that the kinetic energy of the vibrating atoms varies with the temperature. If now the kinetic energy of one atom is increased by increasing its temperature, then the balance of forces between it and surrounding atoms will be disturbed, and the increased motion of this particular atom will result in increasing the motion of surrounding atoms, which in turn will pass on the effect right through the piece of metal.

There is still another means by which energy is transferred through a conductor, and that is by the electrons. It has been shown that the nucleus of the atom is surrounded by planetary electrons travelling in orbits of different sizes and different shapes. When the atoms are located in the crystal lattice the electrons and particularly those of the outer orbits cease to be tied to any particular nucleus, and are free to wander about almost like the molecules in a gas, except that the average concentration of electrons in any part of the metal must remain the same. These electrons similarly transfer energy from one to the other and contribute towards the conductivity of the solid. Any impurity in the metal spoils the continuity of the space in which the electrons move, and, therefore, the impurities reduce the thermal conductivity.

The difference in thermal conductivity of different metals can be attributed to the different construction of the atom, variations in the space lattice, and variations in the number of planetary electrons. Most of the metals which crystallise in the face-centred cubic arrangement are good thermal conductors, soft and good electrical conductors.

Electrical Conductivity—Temperature Coefficient, Superconductivity, Variation of Resistance with Pressure

Each atom of the metal consists of a nucleus and a number of electrons forming a closed system, which is not capable of holding any additional electrons, but some of the electrons in the outer orbits are only loosely held in the system because they form an incomplete series. If now an electron is added to this system one of the original electrons must be passed on to a neighbouring atom, which in turn releases an electron so that the process is continuous. The electric current can, therefore, be considered as the application of a stream of electrons to one terminal of the metallic conductor, resulting in a flow of electrons through the conductor until free electrons are passed out at the other terminal. This process should not be regarded entirely as the passing on of an electron from atom to atom, but rather should be regarded as a general movement, of electrons throughout the piece, upon which is superposed a general drift from one terminal to the other.

The relation between thermal conductivity and electrical conductivity is explained by the fact that the metals which are good electrical conductivities are well supplied with the wandering electrons, which have been shown to contribute

also to heat conductivity. In the latter case, however, there is no general drift or current.

In order to account for differences in electrical resistance or conductivity, it is necessary to imagine that some metals have atoms which part with their electrons quite easily, whereas others part with an electron only with great reluctance.

The decrease in the electrical resistance of a pure metal with fall in temperature is considered to be due to improved contact between the atoms, and, therefore, greater ease in the transfer of the electrons. Superconductivity at temperatures approaching absolute zero has been considered as being due to the atoms being continuously in touch with each other at this temperature, and therefore, offering little or no resistance to the passage of electrons from atom to atom.

An interesting point arises when one considers what happens to the electrical resistance of a metal at its melting point. From the theory it would be expected that on melting as the atoms became more widely separated and lose their definite orientation there would be a markedly increased difficulty in exchanging electrons. This is actually borne out in practice because the electrical resistance of a pure metal increases appreciably as it becomes molten, the increase being of the order of two to one. There are exceptions, however, such as antimony and bismuth, in which the resistance first decreases and then increases.

Variation of Resistance with Pressure

With increased pressure the resistance of pure metals decreases as would be expected, but here again antimony and bismuth are exceptions and go the other way.

V.—Solid Solutions

(References:—" Introduction to Physical Chemistry," by Maass and Steacie; " Metallic Alloys," by Gulliver; " Metals and Alloys," by Evans; " Introduction to Physical Metallurgy," by Rosenhein; " Science of Metals," by Jeffries and Archer.)

Up to the present single pure metals only have been dealt with. It is now proposed to deal with mixtures of pure metals. If a molten metal is added to another molten metal the two will probably form a true solution, although this depends a little upon the temperature. Luckily in most alloy systems of commercial interest the components are mutually soluble in all proportions in the liquid state. There are, however, some systems of only partial solubility in which the liquid if left undisturbed would tend to form two layers, due to the marked differences in weight.

Certain pairs of metals also form solid solutions in all proportions. For instance, copper and gold, iron and nickel, silver and gold. In each of these instances an alloy made of the two metals in any proportion will on microscopic examination be found to consist of only one constituent. There is a marked difference, however, between a solid solution and a pure metal, in that a pure metal has a definite melting and freezing point, whereas a solid solution freezes over a range of temperature, indicating a variation in the composition as freezing continues. This variation can be seen under the microscope by the cored appearance of the crystals, but the metal can be made homogeneous by reheating.

It is evident that in a solid solution the atoms of the second metal must have taken the place of some of the atoms of the first metal, and that the two kinds of atoms have arranged themselves on one crystal space lattice. It is particularly interesting to find that if one metal is completely soluble in the solid state in another metal it can be assumed that the two when solidified separately will each crystallise in the same type of space lattice.

It should be remarked, however, that as the length of the side of the space lattice varies with the different metals the space lattice of the solid solution will be different from that of either of the two constituent metals.

Electrical Conductivity of Solid Solutions

Alloys of the solid solution type are of great industrial importance because of their high electrical resistance. The conductivity of each metal is lowered repeatedly by the addition of the other, the lowest conductivity being reached when the two metals are present in approximately equal atomic concentrations. This increase in resistance can be attributed to the difficulty which the electrons find in passing through the metal and consequent shortening of their paths under the distorted condition of the crystal lattice, and it is also possible that some of the normally easily detached electrons may find themselves fixed under the new arrangement.

Constantan is a typical high resistance alloy consisting of 60 per cent. copper and 40 per cent. nickel. Evidently it is a solid solution, because both copper and nickel crystallise in the face-centred cubic system.

Hardness and Strength of Solid Solutions

It is found that the addition of one metal to another increases the hardness of each, that is to say, the alloys are considerably harder than either of the constituent metals, and this applies equally to the strength of the alloy. This increased hardness may be regarded as resistance to permanent deformation, and since permanent deformation takes place largely by movement along slip planes it follows that increased hardness must be caused by increased resistance to slip.

When two metals are crystallised in the same crystal lattice there is a certain amount of distortion due to the difference in size of the natural unit cell of each metal and, therefore, the increased slip interference due to the staggering of the atoms can be easily understood.

Partial Solution

Leaving apart those metals which form complete solid solutions in all proportions, it can be stated generally that one metal is partially soluble in another, and that usually this solubility increases with increasing temperature. This partial solubility can be regarded as the placing of occasional atoms of one metal in the crystal lattice of the other metal. These occasional atoms may either take the place of the atoms of the other metal or may also be regarded as being retained in the space in between the atoms of the other metal.

In either case a partial distortion of the crystal lattice results. Any excess metal over that which can be taken in solution is deposited independently in its own crystal form and is visible as a separate component under the microscope.

Freezing Point of Metallic Solutions—Lowering of Freezing Point

If a solid pure metal is in contact with its liquid at the freezing temperature then it is known that the number of atoms leaving the solid and entering the liquid is equal to the number of atoms leaving the liquid and entering the solid for equilibrium to be maintained.

Suppose now a small quantity of another metal is added. Usually this second metal is more soluble in the liquid than in the solid, with the result that the liquid is diluted more than the solid by the second metal. The result will be that more atoms will leave the solid and pass to the liquid than leave the liquid and pass to the solid, thus causing a gradual disappearance of the solid state. If, therefore, solidification is to be produced the temperature must be reduced, *i.e.*, the freezing point of the liquid has been lowered by the addition of the second metal. If the added metal is more soluble in the solid state than in the liquid, then the reverse will take place and more atoms will enter the solid than enter the liquid, and the liquid state will tend to disappear so that if fusion is required the temperature will have to be raised, and in this instance the freezing point of the liquid has been raised by the addition of the second metal.

VI.—Metallic Compounds

(Reference:—" Science of Metals," by Jeffries and Archer.)

Metals combine with non-metallic substances, the metalloids, and with other metals, to form definite compounds which play an important part in determining the strength of metals and metallic alloys.

Heat of Formation

When a chemical compound is formed, heat is given out. This is called the " heat of formation." It can be accounted for by assuming that the atoms which make up the compound after being brought into a favourable position for combining are forced to give up their energy of oscillation or rotation, in order to become fixed in the position required by the compound. This energy so given up manifests itself by the emission of heat. Similarly in order to break up this same compound, heat is required in order to energise the respective atoms sufficiently to enable them to break away from their bonds.

Compounds in Solution

There seems to be a matter of some doubt whether a compound actually exists in a solution, although it is known that the solid compound may separate from the solution upon solidification. It is probable that the compound exists in the solution, because the heat of formation can be measured, but for the present purpose it is unnecessary to worry about this point.

Compounds in Solid Solution

Just as one metal may be partially soluble in another in the solid state, so a compound may be partially soluble in a metal in the solid state, and in addition the compounds usually follow the same rule as the metals in that increase in temperature increases the solubility of the compound. When a compound is in solution in a metal it is necessary to assume that the constituent atoms are in some way built in to the space lattice of the metal causing some distortion and some hardening.

When the compound separates from the metal it crystallises in its own crystal form just as an excess of a second metal would do.

Hardness and Brittleness of Compounds

The most important characteristics of the compounds found in alloys are their great hardness and brittleness. Alloys made up entirely of such compounds are usually very hard and so brittle that they are useless for mechanical purposes.

From the mere fact that the compound forms from these atoms, it can be seen that the attraction between the unlike atoms must be very great and able to resist forces tending to separate them. The brittleness as compared with a pure metal can also be explained. In a pure metal if it is assumed that on one of the crystal planes a small amount of slip takes place, sufficient to displace the two portions by a lattice space, then the resulting condition is precisely similar to that previously existing, and the previously existing forces are re-established. If now the compound is considered to slip by a similar distance, it is possible to assume that an atom which was previously opposite to a similar or dissimilar atom will now find itself opposite to a different kind of atom and, therefore, the previously existing forces will not be re-established.

Important Compounds of Metals

Fe_3C.—A carbide of iron known as " cementite." It forms an important hardening constituent in steels.

$CuAl_2$.—The hard strong compound which forms an important constituent in the hardening of aluminium alloys.

Mg_2Si.—Another hardening constituent in light aluminium alloys.

VII.—Metallic Alloys

(References:—" Introduction to Physical Metallurgy," by Rosenhain; " Metals and Metallic Compounds," by Evans; " Handbook of Non-ferrous Metallurgy," by Hiddell; " Metallic Alloys," by Gulliver; " Metaux et Alliages," by Grard and Cournot.)

It is not proposed to deal at great length with the many different classes of alloys found in metallurgy, because they are all fully described in the many text books on the subject, and any useful knowledge must include the detail. It will be sufficient for our purpose to deal with one typical family of alloys only.

Equilibrium Diagrams (Fig. 5)

In the figure the ordinates represent temperatures and the abscissæ represent percentages of the metal (*A*) and (*B*). The left hand side of the diagram represents 100 per cent. of (*A*), and the right hand side of the diagram represents 100 per cent of (*B*). The point (*P*) represents the freezing point of pure metal (*A*). The point (*T*) represents the freezing point of pure metal (*B*). The curves *P*, *Q*, *T*, represent the commencement of freezing for alloys of different composition. For instance, an alloy of composition (*X*) per cent. of (*A*) begins to freeze at the temperature (*V*). A point situated anywhere above the curves, *P*, *Q*, *T*, indicates

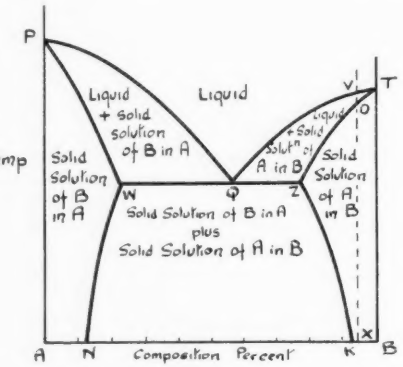


FIG. 5

that at that particular temperature and composition the alloy is in a liquid condition. The curves *P*, *W*, *Z*, *T*, represent the end of solidification of the alloy, thus the alloy of composition (*X*), which commenced to solidify at a temperature (*V*) completes solidification at a temperature represented by (*O*), so that the region between the lines *P*, *Q*, *T*, and *P*, *W*, *Z*, *T*, represents a region of partially solid and partially liquid alloys. From what has gone before one would expect to find that the metal (*B*) was partially soluble in the metal (*A*), and that the solubility decreased with decrease in temperature. This is represented on the diagram by the line *W*, *N*.

In the region *P*, *W*, *N*, *A*, there is a solid alloy which consists of a solution of metal (*B*) in metal (*A*), the proportion of (*B*) being less where the temperature is lower. Similarly, the region *T*, *Z*, *K*, *B*, represents a solid solution of the metal (*A*) in the metal (*B*). It has been seen that if the metal (*B*) is present in excess of the quantity that can be held in solution, then it separates in its own crystal form. The region *W*, *Z*, *K*, *N*, therefore, represents a mixture consisting of crystals of (*A*) with some (*B*) in solution, together with crystals of (*B*) containing some (*A*) in solution.

Presence of a Compound

If the two metals in question form between them a compound when mixed in a certain proportion, the diagram is altered and takes the form indicated in Fig. 6. In this instance the compound corresponds with a composition represented by the point (H), the point (H) being determined by the proportions of the metals required to give the compound, thus Fe_3C would correspond to 6.6 per cent. carbon.

From what has gone before one would expect to find the melting point of the compound to be fairly high, and this is represented in the diagram by the point (R). In order to investigate the effects produced by this compound it is only necessary to divide the diagram into two parts, and consider the portions from (A) to (H) and (H) to (B) respectively as being the diagrams of two metals, except that in this case the metal represented by (H) is the compound.

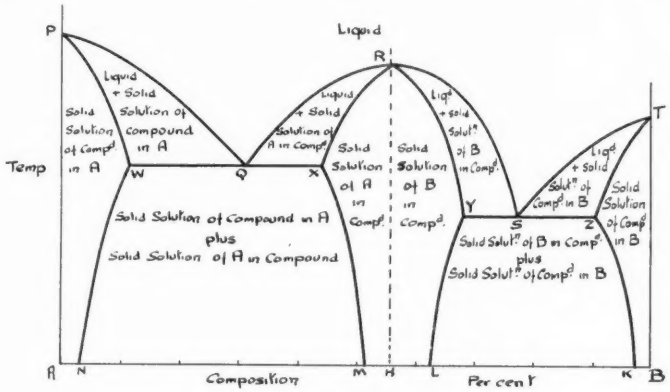


FIG. 6

It is thus seen that the region P, W, N, A, now represents a solid solution of the compound in the metal (A) and the region R, X, M, H, represents a solid solution of the metal (A) in the compound. Also the region W, X, M, N, now represents a region consisting of two kinds of crystals, the first crystals of (A) containing some compound in solution, and the second crystals of the compound containing some (A) in solution. These equilibrium diagrams for alloys are frequently exceedingly complicated, but by starting with a simple diagram and making sure that this is thoroughly understood, it is possible to pass from the simple to the more complicated diagrams without any very great difficulty.

Eutectic

It has been seen that when one metal is added to another there is generally a lowering of the melting point, thus in Fig. 5 the addition of (B) to the metal (A) results in the lowering of the freezing point in accordance with the line (P, Q), which represents the beginning of solidification. Similarly, the addition of the metal (A) to the metal (B) results in the lowering of the freezing point of the metal (B) in accordance with the line (T, Q). There is thus one particular mixture represented by the abscissa of the point (Q) at which the freezing point of the alloy is a minimum. This point is called the " eutectic " point, and represents the alloy of those two particular metals which has the lowest freezing point. It will be seen from Fig. 6 that it is possible to obtain eutectics between metals and compounds.

The Physical Properties of Metals

Up to the present metals have only been considered from the point of view of single crystals. Actually it is well known that a metal consists of a large number of interlocking crystals, and the size and condition of this crystalline structure plays an important part in determining the physical properties of the metals.

The determination of the most suitable crystal structure and the finding of commercial methods for producing the desired condition form important parts of the work of the metallurgist and the engineer. This part of the work is, however, generally fairly well understood, and it is not proposed to enter into any details in this memorandum, which is devoted more to a discussion of the underlying theory of the condition of the metal in the crystal.

VIII.—Hardening of Metals

(Reference:—" Science of Metals," by Jeffries and Archer.)

Hardness is usually determined by an apparatus for measuring the load required to produce an indentation in the surface of the metal. There are a number of machines for this purpose, but they are all covered by one general definition that hardness is resistance to permanent deformation. It has been shown previously that metals possess very great inherent cohesion amounting to figures which cannot be even approached by commercial materials.

The crystalline form of the metal, however, results in a regularity of the atomic arrangement, which gives rise to certain planes of weakness or low resistance to shearing stress. When the external load produces movement along one of these planes the fragments may or may not adhere to each other in their new position. If they do not the failure of the crystal is complete, and the metal is said to be brittle. The plane of weakness is then known as a " cleavage plane."

More generally in the metals commonly used the crystal fragments adhere, and merely slip over each other. The result of such slip repeated on many planes is a measurable permanent deformation. The crystal is then said to be ductile, and the planes of weakness are called " slip planes." The first appreciable formation of slip planes indicates the passing of the " elastic limit." Anything that serves to hinder slip is a source of strength and hardness. The hardening and strengthening of metals by any of the known methods may be considered as due principally to interference with slip.

Hardness by Grain Refinement and Cold Work

Grain refinement, due to the increase of the number of grain boundaries, and increasing complexity of the structure interferes with the slip and, therefore, increases the hardness. In the same way cold working breaks up the crystals and changes their orientation, thus again interfering with slip and increasing the hardness.

Hardness of Solid Solutions

The increased hardness and strength of solid solutions are traceable directly to increased atomic forces and to a roughening of the slip planes due to the distortion of the crystal lattice brought about by the presence of unlike atoms.

Hardness of Metallic Compounds

It has also been seen that metallic compounds are hard and brittle, due to their complicated structure, and the arrangement of atoms in such a way that those of one element are not interchangeable in position with those of another element.

Hardening due to the Presence of a Free Compound

If a hard compound is present as small crystals spread through the body of a metal these hard crystals will tend to prevent slip and produce hardness, but if now it is imagined that the same amount of material instead of being present as crystals visible under the microscope is present as very small particles of submicroscopic size, then it is possible to imagine these tiny hard particles as forming a more effective lock, preventing slip on the slip planes of the crystals.

If a piece of wood is divided up into layers $\frac{1}{8}$in. thick, then a $\frac{1}{2}$in. diameter ball will serve to lock five of the layers preventing slip between these layers. The material in the $\frac{1}{2}$in. diameter ball can now be considered as being more finely divided in the form of 64 $\frac{1}{8}$in. diameter balls. These balls will now serve to lock 65 layers, thus indicating that by having the hard material in a finely divided state a very much larger number of layers can be locked. This provides a useful analogy for explaining the hardening effect of metallic compounds on metals.

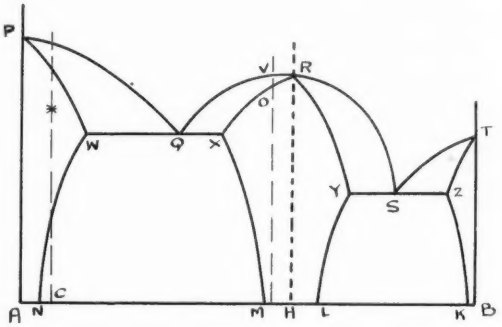


Fig 7

Referring to the diagram for an alloy, consider an alloy of a composition corresponding with the position (C), Fig. 7; then it is known that when the temperature represented by the line P, Q, is reached in cooling a portion of the alloy commences to solidify. Upon reaching the line P, W, the alloy is completely solidified. At any position inside the area P, W, N, A, the alloy is a solid solution of the compound (H) in the metal (A).

Suppose now that from some position in this region the alloy is quenched, then the structure which existed at the temperature before quenching will be initially retained at room temperatures, although with time it may slowly change. In this condition the metal has the hardness to be expected from a solid solution of this composition.

It is possible by a suitable heat treatment to bring about a readjustment of the condition of this metal, and it is known from the diagram that at room temperatures the equilibrium condition of the metal would be a solid solution containing much less of the compound, as represented by A, N, so that in order to reach equilibrium there is a tendency for the compound to be released.

If the heat treatment is correctly carried out this compound can be released in an extremely finely divided state so that it acts as a locking medium on the slip planes of the metal in the manner indicated above. This process is roughly the process that takes place during the hardening of all metals by heat treatment.

IX.—Heat Treatment of Light Alloys

(References:—" Metaux et Alliages," by Grard and Cournot; " The Metallurgy of Aluminium and Aluminium Alloys," by Anderson; " The Aluminium Industry," by Edwards, Frary and Jeffries.)

Certain alloys possess the property of hardening after suitable heat treatment. The best known of these alloys is duralumin, which when heated to about 500°C. and quenched in water is soft, but which hardens with time either at room temperatures or at a slightly raised temperature, depending upon the analysis. This hardening is directly attributable to the presence of a hard compound, and in alloys of the duralumin class this compound may be either Mg_2Si or $CuAl_2$.

From what has gone before it is known that the hardening effect is due to the change in solubility of the compound in the basic metal with change in temperatures. From the curve for the alloy made up of aluminium and $CuAl_2$, it is found that at a temperature of 548°C. the aluminium will take in solution $CuAl_2$ equivalent to 5.65 per cent. of copper, but that at a temperature of 250°C. the aluminium would only hold $CuAl_2$ in solution up to a copper content of 0.5 per cent. (Fig. 8).

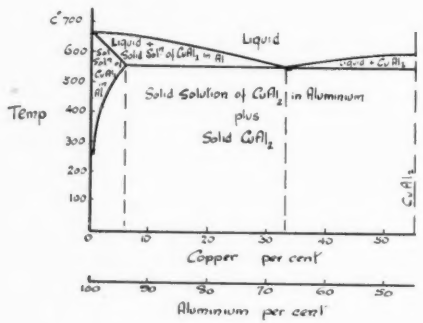


Fig. 8

If, therefore, an alloy containing 5.65 per cent. of copper is heated to 548°C. all the $CuAl_2$ is taken into solution, and if this metal is quenched it will be found to be harder than the fully annealed metal due to the compound in solution, but considerably softer than the metal in its hardest condition.

When this quenched material is heated to a temperature of about 150°C. and held at this temperature for some considerable period, it is found that a decided hardening effect takes place. This hardening has been due to the gradual precipitation of very fine particles of $CuAl_2$, which interfere with any tendency to movement along the slip planes of the crystals. The $CuAl_2$ is not visible under the microscope.

If, however, metal of this same composition is very slowly cooled from the higher temperature, then the $CuAl_2$ deposited from the solution is able to coagulate and form its own crystals of visible size, which are easily apparent under the microscope, and in this condition the metal is very soft. Alloys of a similar type containing magnesium owe their hardening to the presence of Mg_2Si, which acts in a similar manner to the $CuAl_2$ except that it precipitates at room temperatures, so that an alloy which has been quenched from a temperature of about 550°C. gradually hardens itself at room temperatures without further heat treatment.

X.—Heat Treatment of Steel

(References:—" Metallography and Heat Treatment of Iron and Steel," by Saveur; " Metal Progress," September, 1930.)

As mentioned previously, the hardening properties of steel are due to the presence of the compound Fe_3C in the iron and, therefore, in studying the heat treatment of steels it is necessary to study the equilibrium diagram for the alloys formed by iron and the compound iron carbide.

The complete diagram as usually published covers only the iron side of the diagram up to about 5 per cent. carbon content, this being the extent of the diagram which is of practical importance. The diagrams vary a great deal with different authorities, but a good representative diagram covering modern ideas is shown in the attached Fig. 9.

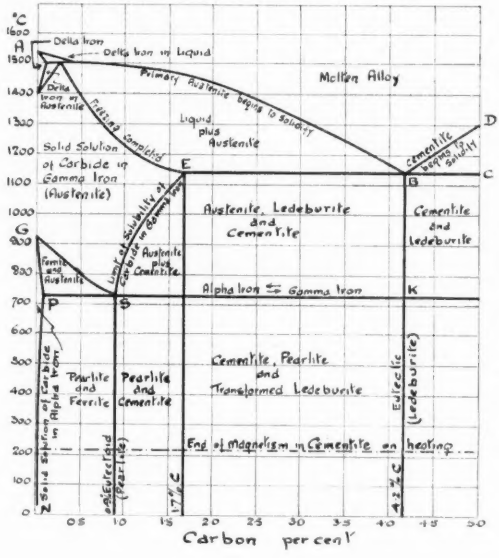


Fig. 9

In studying this diagram it is advisable to consider it in two stages, Fig. 10 and Fig. 11.

Consider the upper part of the diagram with some simplification by omitting some of the lines at the point (*A*). The line *A*, *B*, represents the temperature and composition at which the metal begins to solidify, the temperature being less as the amount of carbon increases.

The point *B* is the eutectic point for iron carbon alloys. In the region *A*, *B*, *E*, the alloy consists of a solid solution of carbide in iron with some liquid. The region between the lines *A*, *E*, *E*, *S*, and the axis *O*, *A*, represents solid solution of carbon in iron. It would, perhaps, be more correct to describe this area as the area of solid solution of Fe_3C in iron. The curve *E*, *S*, represents the limit of solubility of Fe_3C in iron. The area below the curve *C*, *B*, *E*, *S*, represents a mixture of solid iron containing some carbide in solution and solid carbide.

The area from 0 per cent. to 1.7 per cent. carbon represents the range from wrought iron to exceedingly high carbon steels, the region from 1.7 per cent. carbon to 5 per cent. carbon represents the whole range of cast irons from the white irons up to very soft irons containing large amounts of graphite. The separation of Fe_3C into iron and carbon is a complication which occurs in the cast iron portion of the diagram.

The Eutectoid

The point *B* in the iron carbon diagram is a true eutectic. If, however, the lower portion of the diagram is now considered it is found that in the lines *G*, *S*, *E*, there is a construction which would appear to indicate the presence of a eutectic. It is also known that below the line *A*, *E*, *B*, the metal is solid, therefore the point *S* cannot represent a true eutectic, but must have some different characteristic. This point *S* is called the " eutectoid " point because of its similarity to the eutectic. It occurs at a carbon content of about 0.9 per cent. (Fig. 11).

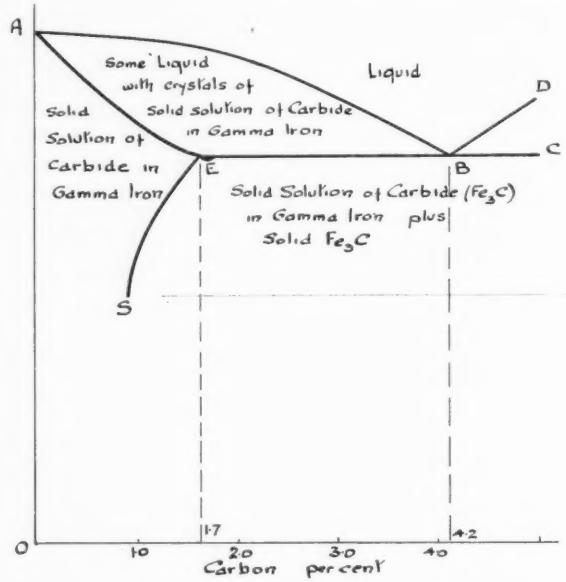


FIG. 10

Upper portion of simplified iron—iron carbide diagram.

The lines *G*, *S*, and *P*, *S*, also need to be explained. Consider a steel containing 0.5 per cent. of carbon, which is being cooled from high temperature, it is found that when a temperature corresponding with the line *G*, *S*, is reached the steel does not change in temperature, although it is still giving up heat, *i.e.*, there is an arrest point in the cooling curve. This point is called the upper critical point. On further cooling, at a temperature of about 700°C. a further arrest occurs when the well-known phenomenon of " recalescence " occurs.

There is also another change which occurs at a definite temperature, and that is the change from the magnetic to a non-magnetic condition, which occurs at a temperature slightly below 800°C. At the higher temperatures the metal is non-magnetic, changing to strongly magnetic at the lower temperatures.

The best way to deal with the steel portion of the diagram is to consider the point *S* as being exactly analogous to a eutectic. Above the lines *G*, *S*, *S*, *E*, the metal consists of a solid solution of Fe_3C in iron. In the portion *G*, *P*, *S*, the iron has commenced to separate out in the form of ferrite. In the portion *S*, *E*, *L*, the carbide has commenced to separate out. The region *G*, *P*, *O*, represents almost pure iron, except that this iron still contains a small amount of carbide as represented by the solubility curve *P*, *O*. The region *O*, *P*, *L*, *M*, represents a mixture of iron and carbide. When the carbide separates from the solid solution during very slow cooling it does so in the form of thin plates of carbide deposited between thin plates of iron. The metallurgical name for the iron is ferrite. When these two are combined in alternate layers the combination is known as pearlite.

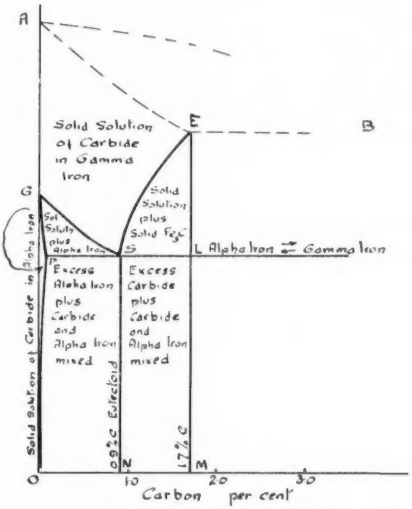


FIG. 11

Lower portion of iron—iron carbide diagram.

At the point *S* the alloy consists entirely of pearlite. In the region *S*, *L*, *M*, *N*, the alloy consists of pearlite with an excess of carbide as cementite. In the region *P*, *S*, *N*, *O*, the alloy consists of pearlite with an excess of iron as ferrite. In the region *G*, *P*, *O*, the alloy consists entirely of ferrite, which may contain a small amount of carbide in solution.

Allotropic Forms of Iron

Above the critical points the iron consists of what is known as gamma iron, in which the atoms are arranged in the face-centred cubic lattice, which is the most closely packed arrangement of atoms.

Below the upper critical point the free iron exists as alpha iron, which crystallises in the body-centred cubic arrangement, which is not so closely packed as the gamma iron, and consequently in passing from gamma iron to alpha iron there is an increase in volume of about 1.5 per cent. due to re-arrangement of the atoms. These allotropic changes account for some of the variations in the equilibrium diagram.

The curve E, S, represents the solubility of Fe_3C in gamma iron. The curve P, O, represents the solubility of Fe_3C in alpha iron, the break in the curve from P to S being due to the change in solubility which occurs in changing from alpha to gamma iron.

Hardening of Steel

It is known from experience that if a piece of steel is quenched from an orange coloured heat it will be hardened more or less, depending upon its greater or lesser carbon content. Consider a steel containing 0.5 per cent. carbon, which has been quenched from a temperature of 900°C. From the diagram it is known that at this temperature and composition the steel consisted of a solid solution of carbide in gamma iron.

During quenching the structure existing at the higher temperature has been retained, but the iron has changed its crystal form from the gamma to the alpha condition, so that the whole metal is in an unstable condition. The carbide which was held by the gamma iron can no longer be held by the alpha iron. It can, therefore, be imagined to have been released *in situ*, that is as very finely divided particles, which, being of hard brittle material, form an effective obstacle to slip, and thus cause hardness in the metal. The structure of quenched steel of this kind is very complicated and does not lend itself well to microscopic examination at ordinary magnifications.

It should be noted that the steel differs from duralumin in that when duralumin is quenched the compound is held in solid solution, and is only deposited subsequently after some fairly long period. With steel there is an allotropic change which alters the crystal lattice. The compound Fe_3C is almost insoluble in the new alpha iron, and is deposited at once in sub-microscopic particles.

If now this quenched steel is slowly heated a re-arrangement will take place, in which the carbide particles will tend to assert their own individuality, and coagulate to form separate crystals, with the result that after re-heating to sufficiently high temperature and slow cooling the normal structure of slowly cooled steel is obtained. Any intermediate stage will have an intermediate amount of hardness corresponding with the well-known grading of hardness obtained by tempering steels. Increase in carbon content, of course, increases the effect produced, and for this reason a carbon tool steel will have carbon content of about the eutectoid composition. At this composition the quenched steel has nearly all the carbide deposited in a finely divided condition, producing great hardness. Any greater carbon content results in excess of free cementite, which is brittle, and any smaller carbon content results in free ferrite, which is soft.

ABSTRACTS AND NOTICES

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Aircraft Design

Performance of Land Aeroplanes, Simple Calculation. (G. Förstner, Z.F.M., Vol. 23, No. 6, 29/3/32, pp. 169-173, 270th D.V.L. Report.) (5.1/24001 Germany.)

The importance of reducing aeroplane tests to standard conditions is emphasised. A number of formulæ, families of curves and abacs (nomograms) are given to facilitate the numerical work. Two worked out examples are given, one for taking off, one for landing. The principles and formulæ are familar, but some of the methods are stated to be new.

Aeroplane Performance, Formulæ and Charts for Calculation. (W. B. Oswald, N.A.C.A. Report No. 408, 1932.) (5.1/24002 U.S.A.)

Three parameters are selected depending on the form resistance of the aeroplane as a whole (total resistance less induced resistance), the span, the thrust h.p., and the total weight. These are combined with the maximum velocity to form non-dimensional parameters. A great mass of aeroplane and airscrew data are expressed graphically in terms of these parameters. Families of curves are drawn to enable aeroplane characteristics to be placed rapidly for comparison.

The real test of these methods is whether they permit of quicker or better comparisons of different types of design, and this can only be judged on the basis of wide experience.

Thirteen references are given.

Type Testing of Aircraft. (A. L. James, Engineering Journal (Suplt. to J. of R. Aer. Soc.), No. 2, Dec., 1931, pp. 7-12.) (5.1/24003 Canada.)

A systematic scheme of type testing is laid down with formulæ of reduction and graphical examples.

Development of Rules for Structural Strength of Aircraft. (H. G. Küssner and K. Thalan, Z.F.M., Vol. 23, No. 11, 14/6/32, pp. 313-318. Extract from 278th D.V.L. Report.) (5.15/24004 Germany.)

An account is given of the historical development of the subject with consideration of the underlying principles rather than of the mass of technical details involved. A diagram shows the prescribed factors plotted against total weight, for Germany, England, America, Italy and the International Commission. The low factors allowed for large commercial machines are interesting, the German minimum being shown as $3\frac{1}{2}$ and the British minimum as 4. Wing construction receives special notice, and a diagram exhibits a number of cases of accident in relation to the dynamic pressures corresponding to the greatest value of steady lift coefficients. A third diagram shows the required load factor in relation to the maximum lift coefficient and the corresponding dynamic pressures which may be imposed by manœuvres. The large variety of rules is justified by the numerous cases that may occur.

Aerodynamical Interference. (E. Ower, J. Roy. Aer. Soc., Vol. 36, No. 259, July, 1932, pp. 531-577.) (5.11/24005 Great Britain.)

The author assembles a large range of experimental examples of aerodynamical interference and endeavours to draw some guiding principles from the detailed results. The most general rule arrived at is that diverging flow is particularly susceptible to interference with increase of turbulence and of head resistance. In particular the flow on the upper surface of a lifting wing in which the flow converges over the forward part of the wing and diverges over the after part, is extremely sensitive to interference effects; a low wing monoplane with the body touching the wing surface is the worst possible aerodynamical arrangement, although suitable fairing between body and wing would reduce the losses. In the discussion it was remarked that the author had sought in the sensitiveness of a diverging stream a unifying principle for the mass of particular illustrations of unstable fluid motion. Without some such guide the mere collection of particular cases might be unprofitable.

Eighteen references are given.

Size of Aeroplanes and Relative Thickness of Wing Section at the Root. (C. Töpfer, Z.F.M., Vol. 23, No. 6, 29/3/32, pp. 165-167.) (5.2/24006 Germany.)

An elementary numerical discussion is given of the decrease in span and surface rendered possible by the use of high lift wing sections. A conclusion is drawn favourable to the use of deeper wing sections than are in ordinary use.

Aerofoils at Negative Angles of Attack. (R. F. Anderson, N.A.C.A. Tech. Note No. 412, March, 1932.) (5.2/24007 U.S.A.)

The characteristics of twenty-four aerofoils are given, at Reynolds numbers 3,100,000, for angles of incidence from $+32$ to $-32°$, enabling designers to calculate stresses in inverted flight. Results are given in tables and graphically.

Four references are given.

Monoplane Wing Profiles: Experimental Researches. (E. Carafoli, Air Ministry (France) Publication No. 8, 1932.) (5.2/24008 France.)

A summary is given of the hydro-dynamics of a wing profile including conformal transformations. A descriptive account is given of the experimental mounting of the wing and a number of researches are published in the form of pressure distribution curves, lift incidence curves, and polar diagrams. In the former the theoretical pressure distribution is plotted, for comparison. The effect of aspect ratio is further considered and a large number of observed pressure dis-

tributions are tabulated. Lift and moment curves are plotted for a number of aspect ratios on different diagrams, and after applying Prandtl's correction for aspect ratio are assembled on the same diagram and exhibit the well known remarkable grouping on a unicursal curve which scatters only beyond stalling point.

Notes on special forms of wings are added.

Wing Sections of Arbitrary Shape. (T. Theodorsen, N.A.C.A. Rept. No. 411, 1931.) (5.2/24009 C.S.A.)

An extension of previous work (Rept. No. 383; See Abst. No. 21/22513). Comparatively simple applications of conformal transformation are not limited to thin aerofoils, but are applicable to any profile which a simple Joukowsky transformation transforms into a curve not departing much from a circle. In the present paper the use of this fact gives comparatively simple approximations for the general expansion in Fourier series. Several examples are worked out and results are shown graphically and in numerical tables.

Two references are given. No reference is made to Munk's paper N.A.C.A. Report No 142, 1922.

Computation of Leading Edge Loads. (R. V. Rhode and H. A. Pearson, N.A.C.A. Rept. No. 413, 1932.) (5.2/24010 U.S.A.)

The destructive effect of concentration of load is illustrated by two photographs of burst fabric at the leading edge, one caused by over-stressing in a dive and the other by entrance of air at the opening of a seam. A formula is derived for pressure distribution at various angles of incidence and two cases are given graphically, one above, the other below incidence for zero lift. The effect of the location of the front spar is also discussed and exhibited graphically. Computed pressure distributions are compared with experimental wind channel results for typical aerofoils. Computed leading edge loads on actual aeroplanes are compared with full scale results for upper wing in two cases and for lower wing in one case.

Four references are given.

Increase of Maximum Lift in Winds and Gusts. (M. Kramer, Z.F.M., Vol. 23, No. 7, 14/4/32, pp. 185-189.) (22.4/24011 Germany.)

The effect of gusts was simulated by setting up a frame containing six adjustable symmetrical aerofoil guides initially parallel to the wind stream but capable of rotation in either direction. The rotation of vanes through 10° produced a deflection of 8.5° in the stream and the corresponding polar curves of the wing were slightly deformed. Continuous photographic records were taken of the variation of the lift with a time scale marking one-fiftieth of a second. Several diagrams are reproduced.

The phenomenon as a whole is complicated and the increase in lift is exaggerated by a lag in the diversion of the air stream from the back of the wing and decreased by the time taken for the vertical gust to reach its maximum value. Results are plotted for different times of transition from still air to vertical gust, and a corresponding factor of decreased effect is also plotted. The mass of the machine also enters into the problem. As might be expected, lightly loaded wings show relatively greater increases than heavily loaded wings which are nearer stalling point. Two cases are exhibited graphically, one a light aeroplane of flying speed 30m. per second, the other a glider with a flying speed of 20m. per second, both entering a vertical gust of 10m. per second in transition distances of 0, 3, 6 and 9m. The assumption of the D.V.L. that wing loads may be doubled appears to be confirmed.

Weight of Aluminium Cantilever Monoplane Wings. (C. G. Brown, Air Corps Inf. Circ., No. 662, 30/10/31.) (5.25/24012 U.S.A.)

Cantilever monoplane wings of corrugated aluminium alloy box-type construction are considered, and a systematic investigation is made of the relation between span, chord, specified load factor and the designed weights and strength of wing surfaces, webs, stiffeners and other constructional details. A large number of dimensions and weights have been worked out and the results are tabulated along with weight estimates in appropriate tables. The results are considered to offer a rough guide only, and reference is made to subsequent work containing more complete discussion of stresses in wings of this type.

Variable Wings. (E. P. A. Heinze, Flight, Vol. 24, No. 20, 13/5/32, p. 417.) (5.658/24013 Great Britain.)

A description is given of the Schmeidler and Makhonine variable wings, with a number of technical details.

See previous Abstracts Nos. 18/21027-8, 20/22020, 23-23464-5-6-7.

Torsion Calculations of a Fuselage. (H. Davies, Flight, Vol. 24, No. 25, 17/6/32, p. 530e.) (5.45/24014 Great Britain.)

On applying the methods of minimum strain energy directly it is found that the result depends upon the difference of two nearly equal quantities. In a modification of the method the small difference is considered directly, so that terms of magnitude comparable with final result are obtained. A numerical example is given.

Undercarriages, Floats and Hulls

Metal Hulls, Design and Construction. (R. J. Moffett, Engineering Journal (Suplt. to J. of R. Aer. Soc.), No. 2, Dec., 1931, pp. 24-30.) (5.56/24015 Canada.)

A descriptive account is illustrated by photographs of methods of construction. In an appendix the Froude law of similarity is discussed and the calculation of the metacentric height is formulated.

Landing Carriages: Drop and Flight Tests. (W. C. Peck and A. P. Beard, N.A.C.A. Report No. 406, 1931.) (5.55/24016 U.S.A.)

Oleo and rubber cord landing gears were tested by static drop and flight tests. Static tests of rubber chord show stress-strain relations and the hysteresis loop. Similar tests are shown graphically on rubber tyres and discs.

Full scale tests on landing carriages were also carried out and such quantities as maximum acceleration, striking force, and work are shown against the total drop.

The effect of acceleration on impact during landing is shown against the vertical velocity at the moment of contact for three types of landing carriage. Another set of diagrams shows vertical displacements against time during a normal landing.

Tests results on pancake landings and 2-point landings exhibit vertical displacement and velocity against time.

Six references are given.

Wheel Brakes and Undercarriages. (S. Scott-Hall, J. R. Aer. Soc., Vol. 36, No. 257, May, 1932, pp. 386-432.) (5.58/24017 Great Britain.)

A large number of brake designs are considered. Photographs and diagrammatic sketches are given and the common underlying mechanical principles

are analysed. Methods of operation are discussed and advantages and disadvantages compared.

The shock absorbing qualities of tyres and carriages are also surveyed and the Oleo pistons and cylinders are specially considered. Diagrams exhibit the loading displacement relations, taking into account velocity and time. Fairing of wheels is discussed and figures of appreciable increase in top speed for several types are quoted. Comprehensive data from recent machines are quoted in tabular form and include useful examples of undercarriage failure.

In the discussion a number of designers put on record the views formed from their own experience.

Airscrews

Screw Propellers in Open Water. (G. S. Baker and A. W. Riddle, Engineering, Vol. 133, No. 3458, 22/4/32, pp. 498-501, Paper Inst. Naval Architects, 17/3/32.) (5.6/24018 Great Britain.)

A comprehensive series of measurements was made on water screws fitted with blades of conventional sections, flat face and circular back, in comparison with sections derived from aerofoil practice. Twenty-seven blades are listed and the variations of section, outline, and rack shown diagrammatically. Two non-dimensional parameters are introduced, one the familar pitch coefficient, ND/V, the other defined by the relation $B_p = NS^{\frac{1}{2}}/V^{2.5}$.

Efficiencies are plotted for systematic changes in the blade form and for values of B_p, 10, 15, 20 and 25. The speeds are also varied from 3.3 to 5 feet per second, and show substantial variation for scale effect.

The conclusion is that an aerofoil section selected for a special value of DN/V should give substantial improvement, *e.g.*, from 0.6 to 0.66, but for unsuitable conditions may show a definite loss of efficiency.

Composite Airscrew Construction. (Tech. Aeron., No. 122, Dec., 1931, pp. 300-308.) (5.656/24019 France.)

The airscrew blade is constructed of wood covered with a duralumin sheath. The whole blade flexes so that the duralumin sheath is not stressed until the wooden core has undergone a finite strain, beyond which there is joint resistance to further flexing.

The design is intended for application to helicopters.

Instruments

Calibration of Pitot-Static Tube at Low Reynolds Numbers. (E. Ower and F. C. Johansen, Proc. Roy. Soc., Vol. 136, No. A.829, 2/5/32, pp. 153-175.) (24020 Great Britain.)

The instrument under calibration was mounted on an arm projecting downwards from a rotating cantilever beam, and moved in an annular channel of square cross section. The arm entered the channel through a circular opening in the roof closed by a rubber seal lubricated with glycerine. The instrument was thus protected from external currents but in its repeated circuits of the closed channel set up following air currents, the determination of which was one of the principal corrections involved. Measurements were carried out at relative air velocities between 50 cm./s. and 725 cm./s. The linear dimension selected was the external diameter of the Pitot tube, .78 cm. Taking the kinematic viscosity of air as 0.15, this gives a range of Reynolds numbers from 260 to 3,800. The corrected results are tabulated and plotted graphically. The coefficient of the tube remains nearly unity for Reynolds numbers not less than 3,000. Below this value it rises slowly to 1.004 and branches at R = 2250. The lower branch slowly decreases to unity, while the upper branch increases to 1.02 at R = 600. Below R = 600 both

branches fall steeply decreasing below 0.96 near R = 300. Scattered points are found between the two branches and an experiment giving points on one branch may on repetition give points on the other branch. The mean value of the two branches differs only by 1 per cent. from unity, so that from R = 3,000 to R = 600 a fair calibration figure can be obtained with an error not exceeding 1 per cent.

Rapid Measurement of Varying Forces. (Z.V.D.I., Vol. 76, No. 16, 16/5/32, p. 382.) (6.26/24021 Germany.)

The elastic deformation of a plate spring moves a rubber membrane which alters the area of conduction and with it the observed resistance of an electrolyte.

The Deformator. (A. V. Huggenberger, Z.V.D.I., Vol. 76, No. 17, 23/4/32, p. 417.) (6.26/24022 Germany.)

The instrument consists essentially of an invar steel girder susceptible of small shear. The shear is recorded on a micrometer, and with appropriate calibration is a measure of the strain of any structure to which the instrument is attached.

The principal application is to the control of deformation in buildings, bridges, embankments and dams.

Chronometers; Stabilisation of Lubricating Oil. (Woog, Ganster and Givaudon, Comptes Rendus, Vol. 192, p. 923-5 (1931); Vol. 181, p. 772-4 (1925). Chem. Absts., Vol. 26, No. 8, 20/4/32, p. 2310.) (6.3/24023 France.)

A suitable antioxygen stabiliser is β-naphthol. As this works only in the dark, the oil must be coloured by the addition of a red dye.

The Pioneer Vibrograph. (Z.V.D.I., Vol. 76, No. 17, 23/4/32, p. 420.) 6.48/24024 Germany.)

On the principle of the seismograph a beam of light is reflected on to a film carried on a rotating cylinder. By giving the source of light an axial motion the record has a mean spiral motion, and a number of spiral turns may be recorded on each film.

The saving in size and weight makes the vibrograph sufficiently compact for mounting on the instrument board.

Cathode Ray Oscillograph. (F. P. Burch, Phil. Mag., Vol. 13, No. 86, April, 1932, pp. 760-774.) (6.48/24025 Great Britain.)

Author's Summary. In Gabor's oscillographic method a known fraction of the voltage to be measured has to be transmitted over a long line and reproduced without distortion, the division of voltage being effected by condensers or condensers and resistances. If the low voltage impedance of the system is divided between the two ends of the line, the condensers may be made from a sixth to an eighth of the capacity required when concentrated at one end only. The field of application of the method is thus greatly extended.

Aerial Navigation—Methods and Equipment. (S.A.E. Journal, Vol. 30, No. 4, April, 1932, pp. 153-158.) (6.5/24026 U.S.A.)

The author discusses instruments for long distance aerial navigation generally. He recommends the aperiodic compass and the directional gyro compass for blind flying in conjunction with the gyro artificial horizon.

A description is given with diagrammatic sectional sketches of apparatus for determining ground speed and side drift. A graduated film driven by clockwork at constant speed across a prism beneath the eye-piece is aligned and synchronised with the apparent ground motion. Reduction tables are given to

facilitate rapid computation. Navigation by observation of celestial objects is also discussed. Two sextants, one designed by the Bureau of Standards and the other by a private company are recommended. A design combining the best points of each is suggested.

Two second-setting watches should be carried, one marking mean solar time and the other sidereal time. Predetermined computation curves permit reduction of a fix from observations of two stars in less than a minute.

An example of reduction is given.

Comparative Measurements of Radiation by Cells and Mirrors. (G. Grescky, Z. Instrumentenkunde, No. 5, May, 1932, pp. 225-229.) (6.86/24027 Germany.)

A brief account is given of the elementary principles and requirements of the method. Seven types of bolometer and thermo elements are tabulated with the principal characteristics and the calculated and measured sensitivities, the two latter being in close agreement.

The method has applications to determinations of the direction of sources or sinks of infra-red radiation; *e.g.* the funnel of steamship (relative source) or an iceberg (relative sink).

Stability and Control

Measurement of the Influence of a Gap between Elevator and Fin on Static Stability and Directional Controllability. (W. Hübner, Z.F.M., Vol. 23, No. 11, 14/6/32, pp. 318-320, 281st D.V.L. Rept.) (7.2/24028 Germany.)

The gap (20mm.) between elevator post and fin post is shown in a dimensioned sketch. The principal characteristics of the aeroplane and engine are specified and shown in scale sketches of side elevation and plan. The relation between the lift coefficient and the elevator position is plotted graphically with gap open and closed. Other diagrams show variation of the required elevator setting against the change in lift plotted as a function of the position of the c.g. both with open and closed slot. The force exercised by the pilot is plotted against dynamical pressure and finally the attitude of the machine is plotted as a function of the same quantity. An appreciable improvement is shown by closing the gap with fabric. The effectiveness of the elevator was increased 25 per cent. on closed throttle and 40 per cent. on full open throttle. In the last case the effort required by the pilot was reduced by 45 per cent. The advantage was especially noticeable in landing.

The closing of the slot by fabric is therefore recommended.

Lateral Stability in Unconstrained Normal Flight and the Required Technical Provisions. (G. Mathias, Z.F.M., Vol. 23, No. 7, 14/4/32, pp. 193-198, and No. 8, 28/4/32, pp. 224-232, D.V.L. Report 272.) (7.2/24029 Germany.)

A summary is given of the usual theory of lateral stability. Expressions are formed for the quantities entering into equations of stability in terms of specified aeroplane coefficients. The additional terms for dynamic stability are written down.

Of the five conditions for general stability the condition for static lateral stability, $E>O$, is of special importance. E is obtained as the small difference of two quantities of approximately equal magnitude, and is very sensitive to small changes in the aerodynamical coefficients. A descriptive account is given of the development of lateral instability. A slight bank is followed by side slip, directional instability, increased bank, and so on. When the departure from steady flight ceases to be small the coupling effect with the hitherto independent longitudinal instability appears, and the mutual relations become extremely complicated.

A successful discussion of coupled longitudinal and lateral instability is attributed to Baranoff and Hoff, L.F.F., Vol. 3 (1929) p. 39.

The influence of flying attitude and constructional data on the conditions of stability are discussed at some length, and suggestions are obtained therefrom for the guidance of designers. The limits of displacement within which dynamical stability is maintained receive consideration. Conditions of dynamical similitude between model and full scale work are laid down.

Twenty-three references are given.

Non-Stalling and Landing Characteristics with Limited Elevator Movement. (F. E. Weick, N.A.C.A. Rept. No. 418, 1932.) (7.2/24030 U.S.A.)

The pull back of the elevator was limited by a stop in a position which prevented spin with the engine cut off. Vertical velocities of aeroplanes were measured with this restraint in operation, and were found to range from 12 to 24 ft. per second with good lateral stability and control.

The comparatively high vertical component involves a long travel shock absorber strut and safe landings were found to be independent of the method of bringing the aeroplane to the ground when the air speed was kept within 15 m.p.h. of the minimum. In gusty air the problem requires further investigation. Photographs of long travel carriage struts are given and air speed and vertical velocity are shown graphically as functions of elevator angles. Two typical flight paths are reproduced showing vertical height against distance with annotations giving the variations in attitude and vertical speed. Landing data are given in numerical tables.

Effect of Images of Trailing Vortices on Flight near the Ground. (E. Tönnies, Z.F.M., Vol. 23, No. 6, 29/3/32, pp. 157-164, Rept. of Aero. Tech. Inst., Tech. High School, Hanover.) (7.3/24031 Germany.)

The mass acceleration of an aeroplane is equated to the thrust of the screw less air resistance and ground resistance. Expressions due to Blenk are written down for the time required to attain flying speed and for the space covered during that time, account being taken of the variable thrust.

A large number of observed starting runs is plotted against the calculated run, the latter being represented by a straight line through the origin. By an arbitrary addition of 50 metres to the calculated values a semi-empirical rectilinear locus is obtained which passes through the centre of position of the plotted points.

In general low wing machines take a longer run than high wing machines. In a second diagram the observed starting run is plotted against the weight per h.p. and under these conditions the low wing aeroplane takes the shorter run, and this is attributed to the reflection of trailing eddies at the surface of the earth.

A full account is given of the methods of observing and reducing the data relative to the starting run. The results are given graphically showing the comparison between high wing and low wing machines. A separate diagram shows the increase of lift at different heights above the earth's surface.

The methods are applied to determine the best incidence and the corresponding lift and air resistance for the shortest starting run. A mathematical discussion by J. Bonder of the effect of the reflection of the fixed vortices in a wing of large span is referred to, and an approximate formula is quoted. The increase of circulation round the wing is shown graphically as a function of incidence and distance from the ground. The maximum increase of lift calculated for an indefinitely large span is 85 per cent.; the maximum increase of lift for finite span is 45 per cent.

From this it is concluded that the effect of proximity to the earth cannot be ignored in calculating starting runs.

Tests on Wing Model with Low Drag Slots. (F. E. Weick and C. J. Wenzinger, N.A.C.A. Rept. No. 407, 1932.) (7.72/24032 U.S.A.)

A Clark Y model wing was fitted with several forms of fixed slot, and the nose tip was finished with different radii increasing progressively. Extensive tables give the measured maximum lift with corresponding incidence and drag, covering a large variety of arrangements. A diagram gives the lift and drag against incidence from $-4°$ to $24°$ for the wing which gives the lowest drag combined with high lift. Up to stalling point of the wing without slot there is moderate decrease in lift and increase in drag. The slot postpones the stalling point from $15°$ to $24°$ and increases the maximum lift from 1.3 to 1.7. In the upper range, $15°$ to $25°$ incidence, the drag of the slotted wing is appreciably lower than that of the unslotted wing.

The object of the research is to produce a design of wing with fixed slot, free from the complication of weight of slot control gear, which maintains fair performance at low incidence.

Four references are given.

Slots in the Wings of Birds. (R. R. Graham, J. Roy. Aer. Soc., Vol. 36, No. 259, p. 598.) (7.72/24033 Great Britain.)

Some interesting data are given on the comparative size of the wing tip feathers in the young and old of various species. A photograph of the wing tip feathers of the willow grouse illustrates the argument that the spread feathers do act as slotted wings, not for safety, which does not arise in bird flight, but for reducing the rising and alighting speeds.

Engine Design

Engine Mounting Stresses. (R. Rodger, Flight, Vol. 24, No. 18, 29/5/32, pp. 376e-376g.) (8.2/24034 Great Britain.)

The sources of stresses in engine mountings are tabulated and a numerical example is worked out to illustrate each case. The origin and nature of gyroscopic couples are illustrated in a simple diagram.

Multiple Engine Arrangements. (A. R. Weyle, Z.F.M., Vol. 23, No. 8, 28/4/32, pp. 213-219.) (8.2/24035 Germany.)

A general discussion is given of the possible distribution of three and more engines on aeroplanes, and is illustrated by photographs from current German practice which exhibit protection for airscrews in seaplanes, and accessibility of power plant of all types for inspection, etc. A photograph of a French four-engine monoplane is included.

The problems of silencing are referred to.

Indicator Diagrams, I.C. Engines, Graphical Analysis. (A. R. Horne, Proc. Roy. Soc., Edinburgh, Vol. 52, Pt. 2, pp. 208-218.) (8.22/24036 Great Britain.)

A graphical method is given of deducing curves of temperature and internal energy from the pressure volume diagram recorded by the indicating apparatus. The method has considerable advantages in reducing the labour of numerical methods, particularly with variable specific heat.

The author makes no reference to the difficulties of mounting the indicator, or of interpreting the indicator diagrams.

Engine Temperature Indicator. (Aero Digest., Vol. 20, No. 4, April, 1932, p. 84.) (8.22/24037 U.S.A.)

A new Weston indicator weighing 19oz. with copper-constantan couples has a range up to 600°F. and is automatically compensated for "cold-end" temperature.

Turbo-Compressor and Supercharger. (F. Wittle, J. R. Aer. Soc., Vol. 35, No. 251, Nov., 1931, pp. 1047-1074.) (8.235/24038 Great Britain.)

The elementary hydrodynamical principles of the turbo-compressor are discussed fully and the equations of adiabatic flow are established.

An interesting point is the existence of a relative eddy between blades, arising from the fact that the fluid fed to the blades is initially without rotation and substantially remains so as it passes between the blades. Stodola has pointed out that this produces an effective circulation round the blade which reduces the amount of energy transformed by the blade but does not produce an additional loss of energy.

The losses in a compressor are discussed and a percentage figure is given for the principal sources of loss.

In discussing engine efficiency the author takes the view that the indicated h.p. is the fundamental physical quantity to be considered, which implies a criticism of the use of brake h.p. commonly expressed as a function of pressure, temperature, and density, as the fundamental parameter in so-called theories of the effect of height upon efficiency. This does not necessarily invalidate them as useful empirical curves. Quantitative relations are worked out for the h.p. required by the supercharger and for the temperature and density limits of applicability.

Methods of drive are classified and briefly discussed. Numerous data obtained from experience with the British Thompson Houston compressor are discussed, and two photographs are reproduced.

See Abstract No. 18/21125, Variation of power with height.

Diesels, Etc., and Accessories

Diesel-Engined Trucks Cross Sahara Desert. (Motor Transport, 11/4/32, p. 403. Autom. Absts., May, 1932, p. 163.) (8.25/24039 U.S.A.)

The Sahara was crossed and re-crossed by a fleet of fully loaded trucks equipped with Diesel engines. A vehicle fitted with Junkers opposed piston engine, built under licence by the Société Lilloise, carried its own fuel supply for the double journey of 4,000 miles.

The heavy fuel suffers no loss by evaporation, while petrol may lose as much as 50 per cent.

Modification to Packard Diesel. (L'Aeronautique, No. 155, April, 1932, p. 121.) (8.25/24040 France.)

A barrel throttle has been incorporated between the combined inlet and exhaust trunk and the cylinder valve. Slow running is obtained by throttling this passage running on all the cylinders, instead of running on full air and only three cylinders. The compression ratio has been lowered from 16 to 14-1.

Pratt and Whitney "Hornet" Type B1. (L'Aeronautique, No. 155, April, 1932, p. 119.) (8.22/24041 France.)

The new model maintains 575 h.p. at 8,000ft. and weighs 1,000lbs. For short periods near the ground 775 h.p. can be obtained. The engine is fitted with an epicyclic reduction gear, in which the planet pinions are mounted on eccentric bushes interconnected by a hexagon linkage so as to equalise bearing pressure and share the torque equally between the planets. A special oil cooler is incorporated in the inductor pipe immediately above the carburettor.

Guiberson 185 h.p. Diesel Engine. (Aero Digest., Vol. 20, No. 4, April, 1932, pp. 74-75.) (8.2/24042 U.S.A.)

The engine is a nine-cylinder air-cooled radial giving 185 h.p. at 1,925 r.p.m., weight 510lbs., fuel consumption 0.45lb./b.h.p./hour. A single valve acts alter-

nately as exhaust and inlet, somewhat as in the Packard Diesel. The fuel system has a single control to vary both quantity and time of injection. A decompression device lifts the engine valves.

The Schwartz Cycle Engine. (Autom. Topics, 23/4/32, p. 728. Autom. Absts., May, 1932, p. 137.) (8.291/24043 U.S.A.)

Turbulence of the charge is created by the injection of additional air into the main charge shortly before the spark passes. The air is compressed to 11 atmospheres by the skirted engine piston with injection by a rotary valve in the cylinder head. Greater economy with ordinary fuel and carburettor and effective combustion of heavy fuels with spark ignition are claimed.

Steam Power Plant for Aeroplanes. (Kalinowski and Klemin, Aviation Engineering, April, p. 31. Autom. Absts., May, 1932, p. 140.) (8.294/24044 U.S.A.)

The Great Lake Aircraft Corporation is developing an impulse steam turbine plant of over 2,000 h.p. intended for installation in large flying boats, using wing condensers and a closed steam circuit.

No details as to weight of plane, air resistance and fuel consumption are given.

New Cylinder for Wright Engines. (L'Aeronautique, No. 155, April, 1932, p. 123.) (8.32/24045 France.)

In the new type E cylinder the exhaust passages and the bronze seats of the sparking plugs are heavily finned to improve cooling and temperature equalisation.

Distribution of Stresses in Single Cranks. (Rotscher and Crumbiegel, Z.V.D.I., Vol. 76, No. 21, 21/5/32, pp. 508-509.) (8.36/24046 Germany.)

Mathar devised apparatus for measuring deflections optically. Stress optical measurements on transparent crank models show certain divergent results. High local stresses are due to the combination of twisting and bending moments.

Resonance Amplitudes in Torsional Oscillations in Crankshafts. (Rembold and Jehlicka, Z.V.D.I., Vol. 76, No. 20, 14/5/32, pp. 480-482.) (8.36/24047 Germany.)

The equation of forced vibrations for the system of crankshaft plus pistons is established, and verified on a model by the Geiger oscillograph. The effect of gas forces is shown approximately by fitting springs above the pistons.

The model also allows such effects as bearing clearance and orientation of the crank throws to be studied.

Cowling

Cowling. (W. H. McAvoy, O. W. Schey and A. W. Young, N.A.C.A. Rept. No. 414, 1932.) (8.426/24048 U.S.A.)

Seven types of cowling were fitted to three fuselages, the form of the cowling being shown by sectional sketches and by photographs. The cowling has two principal effects, (*a*) in reducing the head resistance of the machine as a whole, (*b*) on the quantity and velocity of the cooling air reaching the cylinders. The flying speed of the aeroplanes tested was from 140 to 170 m.p.h. Increase of speed under the best conditions was of the order of 60 m.p.h. Tables of cylinder temperatures at different points are given, and variations of top speeds with the angle of the outer cowling with the thrust line are shown graphically for the three fuselages.

The effect on the rate of climb curves is also exhibited graphically. Excessive heating of the cylinders puts a limit to permissible interference with the supply of cooling air to the cylinders.

Ten references are given.

Lubrication

Oxidation of Mineral Oils. (T. Yamada, J. Soc. Chem. Ind., Japan, 1931, Vol. 34, pp. 493-495 B. Chem. and Ind., Vol. 51, No. 15, 8/4/32, Abstracts, p. 297.) (8.54/24049 Japan.)

Absorption of oxygen by oil at 100°C. is accelerated by contact with $CACl_2$ and retarded by KOH.

The Utilisation of Castor Oil as a Lubricant. (E. André, Bull. Mat. Grasses, Inst. Colonial, Marseille, Vol. 15, pp. 297-301, 1931. Chem. Abs., Vol. 26, No. 8, 20/4/32, p. 2310.) (8.54/24050 France.)

Methods of production are discussed. Only pharmaceutical oil, resulting from the first pressing of the seed, is suitable for engine lubrication.

Oxidation Characteristics of Turbine Oils. (Fellows and Schneider, Power, Vol. 75, pp. 49-52, 1932. Chem. Absts., Vol. 26, No. 8, 1932, p. 2310.) (8.54/24051 Great Britain.)

The general trend of acidity curves in service was similar to those from the oxidation test. There are, however, noticeable exceptions and the laboratory oxidation test is not recommended as a means of predicting the behaviour of oils in practice.

Fuels, Detonation, Pumps, Etc.

Solidified Liquid Fuel. (J. Y. Johnson, B. Patent 370,392, 31/12/30, Chem. and Ind., Vol. 51, No. 28, 8/7/32. Chem. Absts., p. 589.) (8.604/24052 Great Britain.)

A liquid consisting of alcohols, paraffin hydrocarbons and ketones converted into solid form by the formation therein of a voluminous framework mass formed by the interaction of a base, *e.g.*, NH_3, with a high molecular organic acid.

Coal Gas Engine Fuel. (Motor Transport, 11/4/32, p. 412. Autom. Absts., May, 1932, p. 152.) (8.64/24054 U.S.A.)

Ten-ton lorries have been running in Paris on coal gas fuel. Steel cylinders contain the gas compressed to 200 atms. A high compression ratio gives reasonable fuel costs. The range between recharges is about 100 miles. A small emergency liquid fuel tank is carried.

Oxidation of Petroleum Oils in Presence of Analytically Inappreciable Catalysts. (K. J. Ivanoff and N. N. Petin, J. Russian Chemical Society, 1931, Vol. 1, p. 704. Chem. and Ind., Vol. 51, No. 21, 20/5/32, p. 409.) (8.64/24055 Great Britain.)

The oxidisability of Caucasian petroleum by oxygen under pressure is greatly increased by previous washing of the fuel with tap water. Distilled water does not activate the petroleum.

Separation of Normal Decane from Petroleum by Distillation. (J. H. Bruun and M. M. Hicks Bruun, Bur. St. J. Res., Vol. 8, No. 5, May, 1932, pp. 583-589.) (8.64/24056 U.S.A.)

The routine of separation is described, the proportion of decane being about 0.6 per cent.

Knock Rating of Fuels—Comparative Engine Tests. (A. von Philippovich, Erdol and Teer, Vol. 7, 526-9, etc. Chem. Absts., Vol. 26, No. 9, 10/5/32, p. 2582.) (8.645/24057 U.S.A.)

Comparative matching tests were carried out on 18 different types of engine. Atmospheric moisture has a pronounced influence. Under proper conditions of working, multi-cylinder engines gave as reliable results as single cylinder engines. The Armstrong, Delco and German Hanomag engines were found to give results in good agreement.

Internal Combustion Engine Detonation. (A. S. Martin, Oil and Gas J., Vol. 30, No. 33, pp. 16, 92, 94, 1931. Chem. Absts., Vol. 26, No. 8, 20/4/32, p. 2309.) (8.645/24058 Great Britain.)

During detonation, the flame burns so fast that large differences of pressure occur throughout the cylinder. These may cause the edge of the piston to bite into the cylinder wall.

Performance of an I.C. Engine Running on a Mixture of Benzol and Water. (F. Bosnjakovic, Z.V.D.I., Vol. 75, No. 38, 19/9/31, pp. 1197-1201.) (8.646/24059 Germany.)

The thermal properties of the mixture are discussed and plotted graphically for different temperatures and pressures. A numerical example is worked out in application to an engine with a working mixture of steam and benzol vapour. The results obtained from a research engine with different types of mixture are briefly discussed.

Coal Dust Engine: Ignition and Combustion Process. (W. Wentzel, Fuel, Vol. 11, Nos. 5 and 6, May and June, 1932, pp. 177 and 222; translated from Forschungsheft 343, 1931.) (8.68/24060 Germany.)

The experiments described refer mainly to the experimental determination of the ignition lag and its dependence on size of coal particles and temperature and pressure of air into which it is injected. The constitution of the coal, its moisture and ash content are the principal factors. With prepared dust ignition lag between .01 and .03 sec., together with combustion times ranging from .15 to .35 sec. were obtained.

Engine speeds of the order of 100 to 200 r.p.m. should therefore be possible, and were apparently obtained by Pawlikowski with his coal dust engine.

Twenty-four references are given.

Bosch Combined Governor and Fuel Pump. (Autom. Ind., Vol. 66, No. 25, 18/6/32, p. 875.) (8.741/24061 U.S.A.)

The governor, intended mainly for idling, is sensitive and dead beat. Diesel engines do not idle well, minute differences in the injection causing large differences in speed. The governor is cut out by the accelerator pedal over the normal working range, but operates again at high speed, to impose an upper limit on r.p.m.

The Efficiency of Energy Transmission by Resonance. (O. Föppl, Z.V.D.I., Vol. 76, No. 20, 14/5/32, p. 483-484.) (8.765/24062 Germany.)

Efficiency of energy transmission by resonance under the most favourable conditions is less than by steady direct drive. For special purposes such as fatigue tests the principle is applicable by reason of the exclusion of all other periods. The phase relations of the forces are exhibited in vector diagrams.

Pipe Joints without Solder. (Z.V.D.I., Vol. 76, No. 18, 30/4/32, p. 432.) (8.864/24063 Germany.)

A deformable washer is squeezed between the pipe and a conical fitting. The joint is stated to be gas and fluid tight and to stand vibration without loosening.

Purifying Exhaust Gases of Internal Combustion Engines. (German Patent 541,212, 16/3/27. Chem. Absts., Vol. 26, No. 7, 10/4/32, p. 2041.) (8.721/24064 Germany.)

The gases are passed through silica gel or like absorbent and then through a catalyser capable of oxidising CO in the cold.

A.A. Defence and Ballistics

Defence against Air Raid. (F. H. Wagner, Army Ord., Vol. 12, No. 71, March-April, 1932, pp. 334-338.) (9.11/24065 U.S.A.)

Defensive methods against sky raiders are summarised, including aerial barriers, smoke screens, and organised barrages. For general A.A. defence, chief place is given to 3in. 50-calibre 15-pounders, with a vertical range of 31,000 feet and a rate of fire of 20 h.e. shells per minute, mounted on heavy duty balloon tyres. In general the author considers that the effectiveness of modernised A.A. defence is underestimated.

Demolition Bombs. (H. S. Beckmann, Army Ord., Vol. 12, No. 71, March-April, 1932, pp. 341-344.) (9.31/24066 U.S.A.)

The manufacture of welded bomb cases is discussed briefly and photographs show examples of cases which split upon impact from 2,000 feet and other cases which remained intact with slight bulges after impact from 2,000 to 5,000 feet. The methods of design and inspection are briefly discussed.

Ballistic Engineering Problems. (L. Thomson and N. Riffolt, U.S. Naval Inst. Proc., Vol. 58, No. 349, March, 1932, pp. 383-394.) (9.16/24067 U.S.A.)

A descriptive technical account is given of the methods of research applied in U.S.A. to internal and external ballistic problems. A number of remarkable photographs and kinematograph records are reproduced showing the projectile and smoke leaving the gun muzzle, burst flames after impact and penetration and ground impact of the bomb.

Accuracy in Bombing. (Billard, Rev. F. Aeriennes, No. 33, April, 1932, p. 375.) (9.62/24068 France.)

The standard French bombsight is preferred to more accurate but less robust types requiring more highly skilled attention.

Simple Method of Photogrammetric Determination of an Aeroplane Path from a Fixed Station. (O. Lacmann, Z.F.M., Vol. 23, No. 8, 28/4/32, pp. 232-234. D.V.L. Rept. No. 273.) (9.65/24069 Germany).

A method of recording an aeroplane's flight path by successive photographs has previously been discussed (see Abstract No. 17/20319). In the present paper the actual plate is reproduced, together with three diagrams with the different rulings appropriate for transforming the results from an oblique plate to a plane at right angles to the main line of sighting.

Materials, Corrosion, Etc.

Nitrogen Hardening. (J. E. Hurst, Engineering, Vol. 133, No. 3460, 6/5/32, pp. 555-556. Paper read before Iron and Steel Inst., 5/5/32.) (10.12/24070 Great Britain.)

Some results of a general investigation of the hardness and strength of aluminium-chromium cast iron are given. Chemical analyses are exhibited tabularly and micro-photographs of vertical sections show the difference in grain between the hardened outer layer and the main body of the material. Some account is given of machining and running properties.

Corrosion through Cavitation in a Diffuser. (H. Schroter, Z.V.D.I., Vol. 76, No. 21, 21/5/32, pp. 511-512.) (10.125/24071 Germany.)

By using diffusers made of various substances, including bakelite, it is demonstrated that the corrosion is purely mechanical. The gases occluded in the surface layer are compressed into the microscopic interstices and cause disruption of the material.

The "Protal" Anti-Corrosion Treatment for Aluminium Alloys. (J. Barry, L'Aeronautique, May, 1932, No. 156, pp. 151-152.) (10.262/24072 France.)

The alloy is immersed in a slightly alkaline bath containing salts of manganese, vanadium, titanium, etc. A coating is formed of a mixture of the corresponding oxides with aluminium oxide. It is stated that the chromium bath forms a coating of aluminium oxide only, and gives inferior protection.

Protective Painting Tests. (S. C. Britton and U. R. Evans, J. Soc. Chem. Ind., Vol. 51, No. 28, 8/7/32, p. 213 T.) (10.603/24073 Great Britain.)

A preliminary report was issued in 1930. The same general method of exposure has been retained. The present interim report gives the results of inspection of over 2,000 specimens. Wrought iron and copper steel, properly painted, appear to give better service than ordinary steel. Sprayed coatings of aluminium (by the metalisation process) appear to give satisfactory protection for steel specimens.

Surface Coating Materials. (H. M. Johnson, Chem. and Ind., Vol. 51, No. 28, 8/7/32, pp. 587-588.) (10.603/24074 Great Britain.)

Coating materials from earliest times to the middle of the 18th century consisted of natural resins mixed with drying or essential oils. The use of resin and wood oil followed with little change in manufacture and application till the introduction of nitrocellulose lacquers, now almost universal as motor car finishes. Research has been stimulated in synthetic resins, and the quick drying resin varnishes soon available may compete with the nitrocellulose lacquers.

Vacuum Casting. (H. T. Reeve, Bell Tele. No. B. 624.) (10.2/24075 U.S.A.)

A method of casting small ingots of platinum and other metals is described. Successful wire-drawing from 1 cm. diameter down to 0.001 cm. indicates soundness and freedom from cavities.

Tests on Tin Base and Lead Base Bearing Metals. (Jakeman and Barr, Engineering, Vol. 133, pp. 200-202, 1932. Chem. Absts., Vol. 26, No. 8, 20/4/32, p. 2310.) (10.2/24076 Great Britain.)

Bearing metals with either high tin or lead content are comparatively stable, but an alkali metal-lead alloy will dissolve readily in sperm or olive oil.

Generally speaking, high lead alloys produce more friction than high tin alloys.

Beryllium. (K. G. Frank, Sci. Am., May, 1932, pp. 270-271.) (10.234/24077 U.S.A.)

A brief technical account is given of the methods of producing metallic beryllium. Photographs show the general arrangement of the apparatus and some details of the tube of beryllium detached from the electrode. The price is given as $80 a pound, about a third of the cost of a year previously. Some of the physical properties of beryllium and its alloys are mentioned.

Electric Welding. (Z.V.D.I., Vol. 76, No. 21, 21/5/32, p. 497.) (10.28/24078 Germany.)

Electric arc welding is not affected by impurities and is suitable for automatic installations requiring little skill. The quality equals that of gas flame welds.

Ageing of Rubber Diaphragms. (D. H. Strother and H. B. Henrickson, N.A.C.A. Tech. Note No. 409, Feb., 1932.) (10.428/24079 U.S.A.)

A specification is given of four rubber samples manufactured in 1924, mounted from nine months to two years later in an instrument and tested for ageing. Tables show the percentage increase in stiffness and the shift of the zero from time to time over a number of years. A graphical diagram exhibits calibration of a selected diaphragm giving hysteresis curves and increase of stiffness with load at an interval of five years and for temperatures of 24/25°C. and −10°C.

Improvements in material may render such results obsolete, but it is considered that they form a standard of comparison.

Wind Tunnels, Testing Apparatus, Etc.

N.A.C.A. 7 by 10ft. Wind Channel. (T. A. Harris, N.A.C.A. Rept. No. 412.) (11.1/24080 U.S.A.)

The general characteristics of the channel are specified and shown in diagrams. Specification is also given of the equipment. Two photographs show the mounting of the aerofoil. The balance is suitable for measuring rolling moments, and specimen curves are reproduced. The equipment is designed to economise staff labour and is stated to be satisfactory in this respect.

Four references are given.

Theory of Wind Tunnel Wall Interference. (T. Theordorsen, N.A.C.A. Rept. No. 410, 1931.) (11.16/24081 U.S.A.)

Interference is considered with respect to a jet of rectangular section with rigid plane boundaries or within a fluid transition layer from the jet to external fluid at rest, according to the following scheme:—

	Top.	*Bottom.*	*Side.*	*Side.*
(1)	rigid	rigid	rigid	rigid
(2)	fluid	fluid	fluid	fluid
(3)	rigid	rigid	fluid	fluid
(4)	fluid	fluid	rigid	rigid
(5)	fluid	rigid	fluid	fluid

Cases (1) and (3) are also considered with square cross section.

Prandtl's result for a circular tunnel is mentioned and the result is used that a rigid wall may be replaced by a vortex of opposite sign and appropriate strength, while a free jet surface may be replaced by a vortex of the same sign and appropriate strength. In applying the method to a rectangular jet, instead of a single image a doubly periodic set of images is required to replace the boundaries of the opposite sign to the trailing vortex for a rigid boundary and of the same sign for a free jet surface, all being of the same intensity as the original vortex trailing from

the wing tip. To an approximation pairs of vortices of opposite signs may be replaced by doublets. Appropriate summations are carried out for superposing the velocity field due to the doubly periodic set of vortices. Numerical values of the sums are given in a table from which interference effects can be at once obtained.

References are given to Prandtl and Glauert, but none to Rosenhead's elegant application (Trans. Roy. Soc., A. 228, p. 275) of elliptic functions (theta functions), which are obviously appropriate to the discussion of doubly periodic quantities (see Abstract No. 11/11300).

The Wind Channel (Free Jet Type) of the Focke-Wulf Construction Co. (H. Focke, Z.F.M., Vol. 23, No. 11, 14/6/32, pp. 305-308.) (11.1/24082 Germany.)

A photograph of the building, two sectional diagrams of the channel, and photographs of a model mounted in the jet and of the balance are reproduced. Calibration curves are given of the electric drive. A number of technical details are specified. The ratio of the power input of the apparent jet energy per second is .532 with a jet speed of 36 m. per second.

Nine references are given to descriptions of other channels.

Measurement of Power of Air-Cooled Engines. (J. Ducarme, L'Aeron., No. 154, March, 1932, pp. 79-81.) (11.55/24083 France.)

A descriptive technical account is given, with three photographs, of the installation set up by the Belgian Aeronautical Technical Service for the exact determination of the power given by air-cooled engines. The equivalent of the relative wind in flight is supplied by a high velocity jet of cooling air of sufficient diameter.

Testing Materials by Means of Gamma Rays. (R. Berthold and N. Riehl, Z.V.D.I., Vol. 76, No. 17, 23/4/32, pp. 401-406.) (11.47/24084 Germany.)

Gamma rays emitted by certain radioactive preparations penetrate materials of relatively large thickness, say over 10 cm. The advantages of the method are first of all ease of manipulation and testing *in situ*, since the radioactive material is contained in a small capsule; secondly, no skilled attention or supervision is required whilst an exposure is being made.

Disadvantages are loss of definition and impossibility of visual observation by means of the fluorescent screen.

A suitable material for the work is mesothorium, at approximately half the cost of radium. Arrangements have also been made for hiring out the preparation. At the present moment the cost per exposure in the case of 4in. specimens is practically the same as when using an X-ray outfit. Above this thickness, the gamma ray method is distinctly cheaper. It is probable that with increased demand the cost of mesothorium can be reduced very considerably.

Schopper Textile Testing Instrument. (Inst. World, Vol. 5, No. 49, June, 1932, p 3.) (11.45/24085 Great Britain.)

A brief descriptive account is given, illustrated by a detailed photograph. An automatic tension recorder shows the relation between strain and stress. The rate of applying the load is also controlled to meet test specifications.

Airships, Etc.

Airship Design: Application of Practical Hydrodynamics. (R. H. Upson and W. A. Klikoff, N.A.C. Rept. No. 405, 1931.) (12.2/24086 U.S.A.)

A number of formulæ are collected from various sources and the results of numerical computations are for the most part shown graphically. Formulæ are given for inertia coefficients of ellipsoids rotating in a fluid. The following graphical charts are given:—

1. Moments of inertia of ellipsoids rotating in a fluid as a function of fineness ratio.
2. Formulæ only for normal pressure distribution and for integrated forces on a prolate spheroid.
3. Distribution of pressures along the axis of an airship body obtained by the method of sinks and sources and by assuming arcs of ellipsoids.
4. Transverse force per unit axial length, shear and bending moment, plotted against axial position.

Other distributions of transverse forces on various models are compared with formulæ due to Munk. Stability formulæ are also quoted in a form convenient for computation. Frictional forces are plotted against fineness ratios, the minimum occurring at fineness ratios of about 4-5. A number of dimensional formulæ are used, but no great light is thrown by them on the physical problem. A table of inertia coefficients is given. It is remarked that the product of the principal moments of inertia, $A \times B$, is nearly constant over the range considered.

The U.S.S. Macon. (Flight, No. 21, 20/5/32, p. 444, and Aviation, No. 5, May, 1932, p. 233.) (12.1/24087 U.S.A.)

A photograph (*Flight*) shows partial assembly of the main frames of the Macon, the sister ship to the Akron. A photograph (*Aviation*) from another angle shows the tapered tail section ready for attachment.

The U.S.S. Akron. (U.S. Air Services, Vol. 17, No. 4, April, 1932, p. 24.) (12.3/24088 U.S.A.)

The Akron as completed exceeds contract weight by 8 per cent. and falls short of contract speed by 4 per cent.

A Naval Affairs Committee of Congress is investigating this, and allegations of inferior workmanship.

The Akron. (Aviation, Vol. 31, No. 6, June, 1932, p. 275.) (12.3/24089 U.S.A.)

A brief account is given of a cruise of the Akron. Reference is made to the construction of the sister ship Macon. A photograph on the opposite page shows a Navy aeroplane hooked on to the Akron, and the gap in the hull through which it is hoisted into the interior.

Special Navy Plane to be Used with Airship Akron. (Aero Digest., Vol. 20, No. 4, April, 1932, p. 98.) (12.3/24090 U.S.A.)

The machine is a single-seater fighter biplane fitted with 420 Whirlwind engine, duralumin monocoque fuselage, 19 feet long, 25ft. wing span, of 180 m.p.h. max. speed. A number of these are to be carried inside the envelope of the airship.

Electrolytic Generator for Large Quantities of Hydrogen and Oxygen. (Z.V.D.I., Vol. 76, No. 17, 23/4/32, p. 421.) (12.44/24091 Germany.)

The installation produces 200 m^3 H_2 and 100 m^3 O_2 per 900 kw. hours. The overall dimensions are 8 by 4 by 2 metres: weight 70 tons, including elec-

trolyte. Several generators have been in satisfactory operation for over a year, giving gas of high purity.

Wireless

Composite Coil Electrodynamic Instruments. (F. B. Silsbee, Bur. St. J. Research, Vol. 8, No. 2, Feb., 1932, pp. 217-264.) (13/24092 U.S.A.)

The design of composite coil instruments depends largely on the mutual electro-magnetic induction of the coils. A large number of expressions are worked out and a numerical example is given. The methods and results are applicable to wireless design.

Radio Transmission Over Long Paths. (L. V. Berkner, Bur. St. J. Res., Vol. 8, No. 2, Feb., 1932, pp. 265-278.) (13.31/24093 U.S.A.)

A systematic series of measurments of intensities was made on signals from New York to Dunedin, New Zealand, a distance of roughly 9,000 nautical miles. Correlations with the diurnal period and with the annual period were made. The exploration ship " City of New York " was in the neighbourhood of the South Magnetic Pole during a magnetic storm, during which the intensity of practically all signals vanished. The effect was localised in the vicinity of the magnetic pole.

Field Intensity Measurements. (S. S. Kirby and K. A. Norton, Bur. Stan. J. Res., Vol. 8, No. 4, April, 1932, pp. 463-479.) (13.31/24094 U.S.A.)

A large number of measurements with airway telephones and beacons were made, and the falling off in intensity of the signal received is shown graphically as a function of distance from the emitting source. From the results the conductivity and di-electric constants of the earth were determined. The di-electric constant west of the Alleghany Mountains was over three times the value obtained east of the mountains. The experimental results are compared with transmission formulæ obtained elsewhere. The comparison is erratic.

Tuned Rectangular Frame Aerials for Short Waves. (L. S. Palmer, Proc. Roy. Soc., Vol. 136, No. A. 829, 2/5/32, pp. 193-209.) (13.4/24095 Great Britain.)

Experiments on wave lengths of 7.54, 8.65 and 8.8 metres were carried out on a tuned frame capable of expansion and contraction in both directions. A physical theory is formed which takes into consideration wave length, direction of propagation, and dimensions of the frame. It is shown that for each particular height of frame less than one wave length, there are two critical areas of maximum current produced with rapid decrease of current value for increase or decrease of the frame height. The conductivity of the ground enters into the equations and an indirect determination was obtained. The dimensions are determined by the odd roots of two elementary transcendental equations, one for the height and the other for the width of the frame.

Selective Photo-Electric Effect from Two-Component Cathodes. (A. R. Olpin, Bell Tele., No. B. 622.) (13.5/24096 U.S.A.)

Experiments were carried out with gas-treated alkali metal cells and the methods of wave mechanics were applied to the interpretation of the results. The properties are related to the crystalline structure of the material, and the single selective maximum observed in hydride cells and the several selective maxima of oxide and sulphide cells are explained in terms of these structures.

Operation of Vacuum Tubes as Amplifiers. (C. E. Fay, Bell Tele. B. 638, Jan., 1932.) (13.5/24097 U.S.A.)

The writer states that while the majority of radio telephone stations are designed for modulation at a low power level with subsequent amplification of the modulated carrier wave, no comprehensive treatment is available.

Two classes of vacuum tube are considered: " B " with negative grid bias, zero plate current and no excitation grid voltage—power output proportional to square of excitation voltage; and " C ", negative grid bias reducing the plate current to below zero, with no excitation grid voltage—output proportional to the square of the plate voltage. The elementary relations are formed between voltage, current, capacity and impedance for the various partial circuits. The output current is plotted against exciting voltage for a number of technical circuits.

In class " C " amplifiers there is an inflection of the characteristic roughly at the middle of the useful range which gives a good approximation to a linear relation.

Wave Lengths given Off by a Cylindrical Electrical Conductor. (K. F. Lindman, Ann. d. Phys., Vol. 13, No. 3, April, 1932, pp. 358-372.) (13.3/24098 Germany.)

Theoretical expressions, due to Abraham, Oseen and Hallén, are quoted, and the observed wave lengths are compared with the calculated values. For certain dimensions and end-shapes agreement with Abraham's formula is good. For rather thicker conductors with plane ends Oseen's formula gives better agreement. Hallén's formula gives systematically higher values.

Constant Frequency Oscillators. (F. B. Llewellyn, Bell Tele. B. 640, Jan., 1932.) (13.3/24099 U.S.A.)

Increase in the number of broadcasting stations, narrowing of the available band, and tendency towards higher frequencies, where a small frequency change has more serious effect upon quality, all lead to demands for maintenance of constant frequency.

The Piezo electric crystal is the best known frequency regulator. The present paper discusses certain oscillator circuits which have inherent qualities of maintaining constant frequency. Two groups are considered. In the first the effect of resistance is reduced to the lowest figure possible. Alternatively a high impedance is inserted between vacuum tube and tuned circuit. Both devices have the effect of minimising change of frequency with battery voltage. At a critical value of impedance between battery tube and tuned circuit the constant frequency is maintained for limited range of battery voltages. Four arrangements are considered in detail. Diagrams of connections are shown and the usual expressions in complex algebra are formed for the current voltage, etc., relations and the various circuits and partial circuits. Experimental results are shown graphically and exhibit a satisfactory constancy of frequency over a considerable range with suitable choice of circuit coefficients.

Transmission of 1.3m. Wave Signals. (O. Pfetscher and R. Beck, Phys. Zeit., Vol. 33, No. 6, March, 1932, pp. 242-245.) (13.31/24100 Germany.)

The directional properties of short waves are discussed with reference to the practicability of setting up a network of sending stations at high points in Germany for military and police purposes. The calibration of directional intensity at a distance of 55 km. at a height of 7 m. above the earth's surface is reproduced, and shows sharp definition. A diagram of connections and three photographs of the sending and receiving installations are reproduced.

Ultra Short Wave Tubes. (H. Collenbusch, Ann. der Phys., Vol. 13, No. 2, 1932, pp. 191-211.) (13.5/24101 Germany.)

Experiments were made with fourteen tubes producing wave lengths of from 12.6 cm. to 130 cm. A brief specification is given of the arrangement of the apparatus for emission of waves, with a large variety of measurements of current and voltage characteristics presented graphically and in tables.

In the second part theoretical considerations are briefly discussed and characteristics are calculated for comparison with experiment.

A satisfactory theoretical basis is established for the observed phenomena.

Eleven references are given.

Directional Antenna Systems, Graphical Determination of Polar Patterns. (G. L. Davies and W. H. Orton, B. St. J. Res., Vol. 8, May, 1932, pp. 555-569.) (13.4/24102 U.S.A.)

A graphical method is developed of plotting polar diagrams of directional intensity formed by combining arrays. A number of diagrams are worked out.

The labour involved is considerably less than that required for mathematical computation and is further reduced by the special protractor and graphical multiplication charts described.

Long Wave Transmission. (T. L. Eckersley, Proc. Roy. Soc., Vol. 137, No. A. 831, 1/7/32, pp. 158-173.) (13.31/24103 Great Britain.)

The author refers to G. N. Watson's comprehensive analysis for a sharply defined conducting layer representing the Heaviside layer.

Consideration of the electronic mechanism shows that the simple method of geometrical optics are inadequate in dealing with deflecting layers distributed over a depth of 20 or 30 km. Electrons may make many collisions with molecules during the period of a long wave, so that the convection current is in phase and the displacement current in quadrature with the electric force. The author proposes a method which he calls the " Phase integral method " to extend Watson's analysis to a distributed reflecting stratum. The phase integral is formed and a number of mathematical inferences are deduced which are compared with experiment. Fair agreement is obtained for wave lengths between 400 and 1,000 metres. An interpretation of important difficulties is given.

Effects of Topography on Short Wave Reception. (R. K. Potter and H. T. Friis, Bell Tele. B. 668, 1932.) (13.32/24104 U.S.A.)

It was discovered empirically that the placing of the reception station on the brow of a hill in New Jersey sloping towards a distant station in South America effected a marked improvement in reception on 14 m. waves as compared with neighbouring locations. Mean reception strengths are plotted. Similar experiments made with regard to reception on 20 m. waves from England gave less definite results. A theory of the effect of sloping ground as a conducting surface is discussed, and an explanation of the phenomenon is offered in the more favourable disposition of the polar diagram of intensity. The increase of conductivity in the surface of a salt marsh produced an average improvement of 8 decibels (2.5 times intensity) as compared with ground of ordinary conductivity, the respective conductivities being 3.3×10^{-11} and 2×10^{-13}.

Photography, Survey, Etc.

Aerial Survey in Northern Rhodesia. (W. N. Roberts, J. Roy. Aer. Soc., Vol. 36, No. 258, June, 1932, p. 500.) (14.14/24105 Great Britain.)

A compact account is given of the apparatus and methods used, with examples of check astrolabe readings and diagrams illustrating the perspective reduc-

tions. An example is given of the reduction of an oblique photograph showing the topographical details plotted finally on a correct scale. Another set of diagrams shows the steps in the reduction from overlapping photographs to the final sheet.

Optical Requirements of Aeroplane Mapping. (J. C. Gardner, Bur. St. J. Res., Vol. 8, No. 4, April, 1932, pp. 445-455.) (14.4/24106 U.S.A.)

Rapid air survey: A series of successive photographs, overlapping at least 50 per cent. (in practice about 60 per cent.) exhibit an apparent displacement of parallax on all points above the datum plane of the map. This parallax may be used to determine the elevation above the datum plane. In this way the contour lines of the heights are obtained. A careful discussion is given of the distortion of the lenses, the effects of which must be corrected for before the apparent parallax is reduced. A number of curves of distortion are reproduced as functions of the angular distance from the centre of the field. The characteristic of lenses designed for freedom from distortion shows extremely small distortion up to 25° or 30° and negligible distortion up to 10° or 15°. Characteristics of lenses not specially designed show very heavy distortion above 15°. The cost of flying is so great compared with the cost of the camera that lavish expenditure on the lenses is economically justified.

Acoustics

Reverberation Time Measurement in Coupled Rooms. (C. F. Eyring, Bell Tele. B. 627.) (15.2/24107 U.S.A.)

Two rooms were coupled by a window and the sound density is assumed to change abruptly in passing through the window from one room to the other, a condition reached only approximately. Two simultaneous linear differential equations are formed for the rate of decay of sound energy, each with a term coupling the two densities. A general solution is obtained. Experimental measurements were made in a small room of volume 1,447 c. ft., surface 788 sq. ft., coupled with a large room of volume 73,475 c. ft., surface 11,555 sq. ft. The coupling area could be made 19, 34, 59, or 94 sq. ft. The reverberation times were measured at frequencies between 100 and 5,000 cycles per second, and are plotted graphically. Results are interpreted as decay of intensity with time, and curves show the rates for the large room, the small room, and for both rooms coupled together.

The results have application to the noise transmitted through the window of an aeroplane cabin.

Sensitivity to Differences of pitch. (E. G. Shower and R. Biddulph, Bell Tele., No. B. 621, 1931.) (15.2/24108 U.S.A.)

The quantity to be measured is the proportional change in the musical pitch of a note at different frequencies over a range of about 9½ octaves, F = 30 to F = 11,700. A description of the apparatus is given. It comprises a fixed oscillator, variable oscillator, modulator and amplifier, filter, attenuator, and mouthpiece delivering the sound in an otherwise soundproof room. Results naturally vary with the individual, and the results are plotted for frequency variations within the range given above and intensity variations from 5 to 90 decibels. Families of curves are plotted showing perceptible pitch difference as a function of frequency with contour lines of equal intensity, and change of pitch as a function of intensity with contour lines of equal frequency. Other relations are shown graphically. A general result is that recognition of pitch change is most accurate from F = 1,000 to F = 2,000.

Acoustic Filters. (E. Waetzmann and F. Nocther, Ann. der Phys., Vol. 13, No. 2, 1932, pp. 212-228.) (15.2/24109 Germany.)

The problem of the acoustic filter is stated and the physical theory is worked out mathematically. Observed characteristics are plotted graphically and compared with the theory.

Measurement of High Frequency Sound Absorption in Gases. (E. Grossmann, Ann. der Phys., Vol. 13, No. 6, May, 1932, pp. 681-702.) (15.2/24110 Germany.)

The sounds varied in frequency from 3×10^4 to 3×10^5 Herz. In contradiction with the Stokes-Kirchoff theory, the coefficient of absorption varied with the frequency, especially for CO_2 and SO_2. In CO_2 a sharp maximum occurs at 1×10^5 Herz, the absorption being 300 times that predicted by the theory.

Fire Prevention

Prevention of Fire Hazard Due to Backfires. (T. Theodorsen and I. M. Freeman, N.A.C.A. Rept. No. 409, 1931.) (16.05/24111 U.S.A.)

In previous N.A.C.A. work, to which reference is given, a non-return plug in the intake pipe was found to be impracticable, while gauze screens in the carburettor air intake were found to reduce the risks to a small proportion. In the present paper the action of flame arrestors is studied in a special length of intake pipe, containing the flame arrestor and the cylinder. A full description is given of the measurement of air flow, pressure drop, gas temperatures, etc., and the results are shown graphically. A slight loss of volumetric efficiency was noted, but the increase in pumping loss is negligible.

Ten references are given.

Aircraft and the Fire Problem. (R. A. Denne, J. R. Aer. Soc., Vol. 36, No. 257, May, 1932, pp. 433-443.) (16.05/24112 Great Britain.)

The chemical and physical properties of liquids proposed for fire extinguishing are discussed, and practicable liquids are narrowed down to three or four, of which carbon tetra-chloride is the best known, while methyl bromide is suggested as having more suitable qualities.

The mechanical problem of delivering the extinguishing fluid at the seat of the fire is discussed in some detail, with a description of the design finally evolved to meet Air Ministry requirements. About a litre of the liquid is enclosed in a leaden bag and placed in a three-litre chamber in which a slow combustion cartridge produces the desired pressure of about two atmospheres. Details are also given of the automatic releases actuated by rise of temperature in case of fire and by acceleration in case of accident.

The author presents the fundamental elements of the problem in a lucid manner and expresses his belief in extensive future developments.

Stored Combustibles, Protection Against Fire. (W. J. Willenborg, B. Patent 371,021, 13/1/31. Chem. and Ind., Vol. 51, No. 28, 8/7/32. Chem. Absts., p. 589.) (16.0/24113 Great Britain.)

An inert gas is admitted to the tank under automatic pressure control in such proportions as to form an incombustible gas mixture in the tank and pump chamber.

Autogiro

Autogiro, Vertical Descent. (J. A. J. Bennet, Z.F.M., Vol. 23, No. 8, 28/4/32, pp. 219-222.) (17.05/24114 Germany.)

The author makes free use of previous work done in this country, particularly by Glauert and Locke. The development of the working formulæ follows similar lines, but the presentation is interesting, in particular the flow through the rotating blades and round the tips, the velocity through the blades and the diagrams exhibiting the stalled length of blade. Further work on horizontal flight is anticipated.

Towed Flight

Towed Flight. (M. Schrenk, Z.V.D.I., Vol. 76, No. 19, 7/5/32, p. 467.) (17.4/24115 Germany.)

Towing by motor car or aeroplane imposes on the glider different stresses than gliding flight. The different response to controls is also disconcerting. When towed by an aeroplane at the same altitude, a movement of the elevator will cause the glider to rise or fall without appreciable difference in forward speed. When towed by motor car climb is accompanied by increase in forward speed.

Towed flight is not limited to gliders. The starting and initial climb of a heavily loaded commercial aeroplane could be improved by towing. The inclination of the tow rope to the vertical would determine the components of increased lift and thrust imparted by the " tug " to the towed aeroplane.

Gliders Towed by Motor Car. (Luftwacht, No. 5, May, 1932, p. 191.) (17.4/24116 Germany.)

The towed glider is subjected to a considerable increase in stressing which calls for special design with increased factors of safety. The towing of normal gliders is forbidden by the German Gliding Association.

Pilots, Matters Affecting

Increase of Hydrostatic Pressure in the Blood Due to Mechanical Accelerations. (H. v. Diringshofen, Z.F.M., Vol. 23, No. 6, 29/3/32, pp. 164-165.) (19.29/24117 Germany.)

Consideration is taken of the height of the organ affected relatively to the heart in the sitting position and in the prone position. Under a relative acceleration of 5.5 g. the pressure of the heart of an aviator in the sitting position can be increased by 70 mm. mercury. Much smaller pressures are produced in the prone position, which is therefore more favourable for supporting high accelerations.

Preventive Medicine in Aviation. (E. G. Rawlinson, J. Roy. Aer. Soc., Vol. 36, No. 256, pp. 366-373.) (19.29/24118 Great Britain.)

A concise summary is given of the incidence of medical services on aeronautics, and a brief note on aeronautical transport applied to health services. The most important section of the paper deals with sanitation, quarantine, etc.

Twenty-two references are given.

Catapults. (Engineering, Vol. 133, No. 3457, 15/4/32, pp. 447-449, and No. 3458, 22/4/32, pp. 479-480 and p. 488.) (20.14/24119 Great Britain.)

A descriptive account is given of the design and construction of catapult launching gear for aeroplanes, illustrated with two photographs and general arrangement drawings.

Airports, Planning and Lighting

Aerodromes. (J. Dower, Secy., R.I.B.A., J.R. Inst. British Architects, Vol. 39, No. 13, 30/4/32, pp. 501-515.) (20.2/24120 Great Britain.)

The concluding paragraph summarises the discourse (before the Royal Inst. of British Architects.) The problem of aerodrome planning bristles with structural problems for the engineer, with costing problems and land problems for the surveyor, and with technical and aeronautical problems for the specialist. High praise is given to German designers, where the architect is also an engineer. The necessity of early selection and reservation of the landing ground itself and of the surrounding places raises problems of town planning.

Photographs and plans are given of representative German and American aerodromes, with one French example and with Croydon as the only British representative airport. The Germans are praised also for general design and the Americans for mechanical ingenuity.

A discussion follows.

Airport Lighting Abroad. (E. Marcotte, Rev. Ind., Vol. 61, pp. 86-90, 142-6, 269-74, 1931. Chem. Absts., Vol. 26, No. 8, 20/4/32, p. 2303.) (20.15/24121 Great Britain.)

The article deals mainly with modern practice in Germany and U.S.A. and describes various forms of compressed gas lighting.

Aerodynamics and Hydrodynamics

Eddies in a Viscous Fluid with Transverse Velocity Gradient. (W. Lange, Ann. der Phys., Vol. 13, No. 1, 1932, pp. 9-37.) (22.1/24122 Germany.)

A brief historical review is given of the various unsuccessful attacks on the problem. Two-dimensional flow between parallel planes is discussed along familiar lines. Simplifications of the equations of viscous fluid motion are made: and types of periodic disturbance are assumed; the analysis leads to lengthy expansions; numerical values are obtained in particular cases, and the disturbances are plotted graphically. The author considers that his results give a qualitative idea of the actual phenomena produced by combined action of instability and viscosity. It is difficult to assess the value of such partial attacks on the problem.

Turbulent Flow, Observation with an Ultra-Microscope. (A. Fage and H. C. H. Townend, Proc. Roy. Soc., Vol. 135, No. A. 828, 1/4/32, pp. 656-677.) (22.1/24123 Great Britain.)

A description is given of the mounting of the microscope for observation of the distribution of velocity along a square pipe. The ordinary particles found in tap water served as indicators, and a large proportion were small enough to show Brownian movements in the water at rest.

The maximum values of the periodic velocity superposed on the mean steady velocity were observed, and the maximum inclination of the velocity axis in different planes was also determined. The velocity distributions are exhibited graphically. The flow near the fixed boundary was not steady, sinuous motion being maintained to within 1/40,000 in. from the wall. A more careful definition of the laminar motion usually assumed to exist near the boundary is therefore required.

In a note (pp. 678-684) on the foregoing paper, Prof. G. I. Taylor compares the velocity near the wall with the velocities calculated and observed in his experiment on motion between rotating co-axial cylinders. He shows that his own results reproduce many of the features observed by Fage and Townend, an important step in the elucidation of the nature of turbulent motion.

A Form of Free Jet of Small Contraction with Axial Symmetry. (H. Reissner, Z.A.M.M., Vol. 12, No. 1, Feb., 1932, pp. 25-35.) (22.1/24124 Germany.)

The jet is surrounded by a fluid of equal density, and compressibilty is neglected.

The principal mathematical difficulty consists in meeting the boundary conditions of equilibrium with the surrounding fluid at the surface of separation, which is initially indeterminate. The previous work neglects the contraction of the stream, and the main object of the present paper is to take account of the contraction. The differential equations of fluid motion are transformed to cylindrical co-ordinates and particular solutions are found in terms of Bessel functions of the first and second kind and of orders zero and unity. By superposition of solutions a result is obtained as an infinite series which satisfies the boundary conditions. The result gives a correction for the contraction of the jet, which may not be negligible, but no numerical result is given.

Transport of Vorticity and Heat Through Fluids in Turbulent Motion. (G. I. Taylor, Proc. Roy. Soc., Vol. 135, No. A. 828, 1/4/32, pp. 685-702.) (22.1/24125 Great Britain.)

Equations of a hypothetical mean motion are derived by the author from considerations of transport of vorticity by the superposed cyclic motions, or eddies.

Equations of a similar general nature were obtained by Prandtl from considerations of transport of momentum by the same agency. Transfer of heat and distribution of temperature involved modified considerations.

The experimental distribution of velocity and temperature by Fage and Falkner is given in an appendix. The results are plotted for comparison with the calculated distributions given by Taylor's and Prandtl's assumptions.

The closer fit over the greater part of the curve is held to support Taylor's hypothesis, but the complete change in the form of the curve at the outer boundary of the wake indicates a serious failure of the fit and requires amendment of the results calculated from the assumptions or of the experimental results.

American Measurements of Heat Transfer in Laminar Flow. (H. Kraussold, Forschung, Vol. 3, No. 1, Jan.-Feb., 1932, pp. 21-24.) (22.1/24126 Germany.)

The experimental results obtained by American observers are plotted and compared with two empirical formulæ based on dimensional considerations involving Pécléts number and due to Léveque and to the author. Both formulæ give straight lines when plotted on a logarithmic scale, and the author's formula gives distinctly better fit.

Heat Transfer from a Horizontal Pipe to a Stream of Water. (G. Ackermann, Forschung, Vol. 3, No. 1, Jan.-Feb., 1932, pp. 42-50.) (22.2/24127 Germany.)

A differential equation is formed for the flow of heat and is solved in elementary transcendental functions. The calculated results are plotted and compared with experiment and formulæ due to Nusselt. A three-dimensional perspective figure shows the transference of heat as a function of wall temperature and temperature of the air. Sectional drawings show the mounting of the experiment, and some of the details.

Motion of Fluid in the Boundary Layer of a Rotating Disc. (F. Busman, Forschung, Vol. 2, No. 9, Sept., 1931, pp. 335-339.) (22.3/24128 Germany.)

A brass disc of 250 mm. diameter and 4 mm. thick was mounted on the shaft of a hand drill and rotated at velocities of from 600 to 1,100 r.p.m. The critical value of Reynolds number is given as $r^2\,\theta/\nu = 3 \times 10^5$. A pigment was introduced at the axis and spread itself over the plate. After rotation the pigment left a series of approximately logarithmic spirals on the disc. Empirical formulæ due to v. Karman are applied and give fair agreement.

Convection Currents Set Up by a Hot Vertical Plate. (W. S. Kimball and W. J. King, Phil. Mag., Vol. 13, No. 87, May, 1932, pp. 888-906.) (22.4/24129 Great Britain.)

The height of the plate is limited to 60 cm., the temperature to 115°C. With deeper plates it is found that turbulence sets in, and the results given in the paper do not apply. Certain experimental relations between distance from plate, temperature, and velocity are used to construct equations of heat flow and of convection current velocity fields. Expressions are found for the rate of work, transfer of heat, and the velocity and temperature fields.

Six references are given.

The Divergence of the Flow from the Surface in a Turbulent Boundary Layer. (E. Gruschwitz, Z.F.M., Vol. 23, No. 11, 14/6/32, pp. 308-312.) (22.4/24130 Germany.)

In a previous paper the author attempted to render the mathematical representation of the turbulent boundary layer tractable in the case of two-dimensional flow which was steady outside the boundary layer. Since practically nothing is known about the detailed motions in a turbulent fluid it was necessary to fall back on approximations derived from experimental measurement. The present paper is a brief account of the work. The starting point is an approximation due to v. Karman, introducing a new variable of the dimensions of length and of the order of about a tenth of the depth of the boundary layer in the case of a plane plate. The equation is transformed and solved numerically and the results are compared with experiment. The agreement is excellent.

The introduction of empirical forms and coefficients suggests an exercise in fitting equations to experimental curves rather than a physical explanation.

Air Flow. (W. S. Farren, J. Roy. Aer. Soc., Vol. 36, No. 259, June, 1932, pp. 451-472.) (22.4/24131 Great Britain.)

The paper is chiefly concerned with methods of rendering the fluid lines visible by means of indicators. The vapour of titanium tetrachloride is one of the more convenient indicators.

Numerous examples are shown of the formation of eddies at discontinuous surfaces, the formation of periodic eddies, the diversion of the flow from the surface of a wing, etc.

The prevention of this diversion by sucking away the boundary layer after Prandtl's method is also illustrated. The value of guide vanes at sharp bends in pipes and channels is also shown. A useful discussion follows in which the suggestion is made that a large wind channel should be set aside expressly for visual observations of flow.

The Effect of Temperature on Skin Friction. (J. H. Lamble, Engineering, Vol. 133, No. 3457, 15/4/32, pp. 470-471.) (22.4/24132 Great Britain.)

Measurements were made of the resistance in a water channel of a long thin brass plate (124 by 17.8 by 0.317 cm., running smoothly to sharp edges with a taper of 1 in 8) at velocities from 30 to 60 cm. per second, temperatures from 5 to 35°C., and with viscosities varying from 0.015 to 0.0066 in round figures. The density only varies from unity to .994, so that kinematic viscosity is numerically nearly equal to the absolute viscosity. The non-dimensional quantity, resistance divided by the product of density and velocity squared, is plotted against Reynolds' parameter in the usual way. Observations were made at seven different temperatures and five different velocities. They do not lie along a unicursal curve but on a network formed by two families of smooth curves, one of iso-velocities, the other of iso-thermals.

This implies a departure from dynamical similitude, possibly by reason of imposed vibrations, to which this type of experiment is known to be sensitive over a range of Reynolds' parameter.

The author offers an explanation which appears to deny in fundamental detail Osborne Reynolds' principle of dynamical similitude.

Distributions of velocity are also shown graphically.

Flow of Highly Rarefied Gases Through Tubes. (P. Clausing, Ann. der Phys., Vol. 12, No. 8, 1932, pp. 961-989.) (22.5/24133 Germany.)

From the kinematic theory of gases expressions are obtained for the flow in the form of an integral equation, which involves the error function. Dushman's form, which is appropriate for long tubes, is shown to be a rough approximation for short ones. In special cases numerical solutions can be found for the integral equation. Applications to high vacuum pumps are considered, and a table gives the numerical relations between the pump characteristics and the vacuum obtainable.

Experimental Determination of the Boundary Layer. (O. Cuno, Z.F.M., Vol. 23, No. 7, 14/5/32, pp. 189-191.) (22.6/24134 Germany.)

A diagram shows seven pitot tubes arranged in a carrier in a vertical series with nozzles pointing upstream, approximately parallel to the tangent of the wing profile. The whole apparatus is movable in the plane of the chord. The velocities were deduced from the pressure readings and are plotted graphically for ten heights from 25 to 150 cm. from the surface of the wing. The boundary layer, limited approximately by the knee of the velocity curves, is drawn in the same diagram. Velocities are calculated from empirical formulæ due to v. Karman, and show excellent agreement from the leading edge to .65 of the chord, beyond which point the curves diverge.

Ship Waves. (T. H. Havelock, Proc. Roy. Soc., Vol. 136, No. A. 830, 1/6/32, pp. 465-471.) (22.1/24135 Great Britain.)

Expressions are formed for the disturbance of the surface level along a deep hull by a vertical edge forming a discontinuity in the lines of the hull. The effect of distributing the change of line over different lengths of the hull is also considered. The results are shown graphically for a sharp edge and for three different lengths of distribution of the change of angle along the hull line. The results are applied to show changes in wave profile and are exhibited graphically for a sharp corner and for seven different lengths of distribution.

The author states that the various approximations introduced, in particular the smoothing out effect of the friction belt, render the results unsuitable for direct comparison with experiment. Some idea should be given, however, of the smoothing effects produced.

Elasticity of Materials

Plastic Flow of Mild Steel. (K. Hohenemeser and W. Prager, Z.A.M.M., Vol. 12, No. 1, Feb., 1932, pp. 1-14.) (23/24136 Germany.)

A so-called "deviator tensor," S_0, is formed as the difference between the general stress tensor and the cubical stress tensor. V. Mises considered the relation $S_0^2 = 2K^2$ as invariant where K is the plastic limit under pure shear and under certain conditions this is valid when the range of strain is not too great. The author forms the corresponding stress tensor, and obtains a relation of which Sainte Venant's and Prandtl's formulæ are particular cases. The physical interpretation of the relations is exhibited in a number of diagrams and is considered by the author to correspond to observed anisotropic qualities which appear under the conditions of his experiments on thin steel tubes subjected to extension and torsion. The question is left open whether similar types of anisotropy appear in other metals, and particularly in single crystals.

Twenty-two references are given.

Elastic Hysteresis in Iron Bars. (G. H. Keulegan, B. St. J. Res., Vol. 8, No. 5, May, 1932, pp. 635-656.) (23/24137 U.S.A.)

In continuation of previous work the elastic hysteresis in new bars was determined experimentally by the rate of damping of vibrations. Theoretical relations are discussed and expressions are obtained for the rate of energy loss. The agreement appears to be close.

Properties of Some Materials under Reversals of Bending Loads. (M. Hempel, Forschung, Vol. 2, No. 9, Sept., 1931, pp. 327-334.) (23/24138 Germany.)

Extensive measurements were made of damping of vibrating bars. The air damping was determined separately and the difference representing internal hysteresis is shown graphically as function of the effective amplitude, the latter being taken as proportional to the boundary stress. The materials dealt with include Siemens-Martin steel, Böhler steel, brass, and aluminium alloys. Typical fractures are shown in various metals and the run of the line of fracture is discussed. When the maximum load lies below the ultimate strength under alternating stress the damping decreases with decreasing load to a well-defined minimum. When the ultimate breaking load has been exceeded this minimum is no longer reached, and failure to reach it indicates that the breaking load has been exceeded without proceeding to actual rupture.

Stability of Thin Strips of Material under Shearing Forces in the Plane of the Strip. (Gough and Cox, Proc. Roy. Soc., Vol. 137, No. A. 831, 1/7/32, pp. 145-157.) (23/24139 Great Britain.)

A description is given of the mounting of the experiments and a large number of results are recorded graphically and in tables. With corrections of certain effects due to imperfect mounting agreement with Southwell's results is satisfactory. Difficulties in reduction of the experimental values are discussed.

Comparison of Flow Potential and Slip Theories of Plastic Strain. (A. Reuss, Z.A.M.M., Vol. 12, No. 1, Feb., 1932, pp. 15-24.) (23/24140 Germany.)

General expressions are formed for the difference between total strain and plastic strain.

Two theories are compared; in the former a potential function is assumed for the plastic flow; in the latter the plastic strain is considered as due to mutual slip of crystal planes. The conditions assumed by V. Mises and by Moore are

compared and the resulting relations are exhibited graphically for comparison. The run of these relations is so different that experiment should indicate without difficulty which lies nearer the physical facts.

Deflection of Beams and Struts. (H. H. Jeffcott, Phil. Mag., Vol. 13, No. 83, Feb., 1932, pp. 310-322.) (23/24141 Great Britain.)

In the usual expression for the radius of curvature the slope is considered small and the square of the slope is neglected. The author works out a number of second approximations taking into account the first term in the usual expansion in series and shows that the maximum deflection to a second approximation is double that obtained by the usual first approximation.

Stress Optical Investigation of Structures. (L. Föppl, Z.V.D.I., Vol. 76, No. 21, 21/5/32, pp. 505-508.) (23/24142 Germany.)

The apparatus used in the laboratory of the Munich Technical High School is described and illustrated by a photograph and diagram.

An example of the distribution of the isoclinic lines is given with a field of principal stresses derived therefrom.

The method is substantially restricted to problems which do not depart much from two-dimensional conditions.

In three-dimensional problems some idea of stress concentration may be given intuitively.

Fourteen references are given, including Coker and Filon's text-book, in which there is a comprehensive bibliography.

Torsional Stiffness and Strength of Aeroplane Structural Parts. (H. Hertel, L.F.F., Vol. 9, No. 1, 1/8/31, pp. 1-56.) (23/24143 Germany.)

1. The apparatus installed and methods of making and reducing measurements are described and illustrated with diagrams and figures. The influence of time of loading and of hysteresis loops is taken into account in defining experimental relations.

2. The elementary mathematical theory of the torsion of elastic prisms is summarised, and the hydrodynamical analogy and Prandtl soap film analogy are introduced. Box spars with thin walls and of a hollow square, rectangular and trapesoidal section with angle stiffeners are investigated systematically. The mounting of a test specimen is shown in a photograph. A number of specimens tested are shown in dimensioned sketches and the results of the tests are recorded graphically in tables.

The buckling of the walls was measured and the contour lines resembled those obtained by Southwell (Proc. Roy. Soc., p. 52, 1932) and by Bergmann and Reissner (Z.F.M., Vol. 23, p. 6, 1932; see Abstract No. 23/23452).

The effect of bulkhead panels in altering the run of the torsional stresses along the spar is exhibited graphically. Consideration is then given to spars formed of circular or oval tubes with internal packing acting as flange stiffeners. The test results are reproduced in diagrams and tables.

Consideration is given to a third class of spars with heavy flanges connected by thin webs. Special forms are discussed briefly.

3. Tubes with thin walls without internal packing are considered both with simple and multiple connected sectional areas. A number of formulæ are derived. A procedure is given for the determination of the elastic axis of the spar by experimental methods. The methods outlined above are applied to the

determination of the torsional strength of complete wings. A large number of experimental results are assembled in graphical representation and tables. Cases of local buckling and failure are illustrated by photographs.

Thirty-five references are given.

Calculation of Aeroplane Spars under Buckling Stresses. (A. Teichmann, L.F.F., Vol. 9, No. 3, 30/12/32.) (23/24144 Germany.)

This paper, of fifty pages, contains a compendium of formulæ and numerical tables for the calculation of buckling loads in aeroplane spars, taking into account the effect of the ribs, variation of section, departure of point of support from the straight line, etc. The work may be considered as a generalisation of the methods associated with Berry functions, and the latter appear in the form given by Muller-Breslau in Germany, with extension to include the influences referred to. The expressions, as might be expected, become extremely heavy, and the numerical work is correspondingly lengthy. Extensive supplementary tables are given to facilitate the numerical computations.

Worked out examples are exhibited graphically and show the results obtained by different methods, and the relations of the assumptions made to those for which the results would be exact.

Fifty references are given.

Duralumin Columns of Equal Angle Section, Comprehensive Strength. (E. E. Lundquist, N.A.C.A. Tech. Note, No. 413, March, 1932.) (23/24145 U.S.A.)

A table of buckling strengths of duralumin open channel sections published by the U.S. Army Air Corps and reprinted in Niles and Newell's " Airplane Structure " is extended by tests of angle sections of equal arms. Taking the length divided by the minimum radius of gyration of section as an independent parameter, test results are plotted and compared with Euler's buckling formula. For large values, as is to be expected, Euler's formula gives a useful approximation. At lower values of the parameter the departure of test results from Euler's formula indicates that the elastic limit has been passed before failure occurs, and a correlation is required between the yield point under simple compression or extension and buckling yield. Such empirical curves are shown for the guidance of designers. Further systematic test work on different sections is required.

Five references are given.

Strength Tests of Rods and Wires at Low Temperatures. (F. Pester, Z. Metallk., Vol. 24, No. 5, May, 1932, pp. 115-120.) (23/24146 Germany.)

Mechanical properties of copper, bronze, aluminium alloys and steel are improved by low temperature down to $-60°C$.

Strength Measurements on Complete Ships. (Z.V.D.I., Vol. 76, No. 19, 7/5/32, p. 468.) (23/24147 Germany.)

Two scrapped U.S.A. 1,200-ton destroyers, of identical design, were tested to destruction in dry dock, one supported at the ends and loaded amidships, the other loaded at the ends and supported amidships. In each case the longitudinal members failed by buckling under compression.

Miscellaneous Unclassified

Table of Values of Jacobi's Zeta Function. (L. M. Milne-Thomson, Proc. Roy. Soc., Edinburgh, Vol. 52, Pt. 2, pp. 236-250.) (24148 Great Britain.)

Tables of $Z(u/m)$ are given for values of u from 0 to 3 at intervals of 0.01, and for values of m from 0 to 1 at intervals of 0.1.

Vision from Tanks. (R. J. Icks, Army Ord., Vol. 12, No. 71, March-April, 1932, pp. 319-323.) (24149 U.S.A.)

The methods of providing vision by narrow slits, stroboscopes and periscopes are discussed. Apart from actual danger to the personnel, bullet splashes are the greatest trouble and rapidly smear all glass. The transparency of shatterproof glass is rapidly destroyed by impact and in all cases a supply of spares must be carried to replace chipped and bullet splashed plates.

Bird Wings. (G. V. Lachmann, J. R. Aero. Soc., Vol. 36, No. 256, pp. 374-379.) (24150 Great Britain.)

An analysis is given of the comparative loadings of wings of birds. Relative weights and wing loadings are plotted on logarithmic scales, and empirical relations are obtained in a purely arbitrary manner by grouping along straight line loci. Some aeroplane weights and loadings are added for comparison. The tendency in birds and aeroplanes is to increase the wing loading with increasing total weight. The author considers that certain wing feathers act in the same manner aerodynamically as aerofoil slots.

Flight in Nature and Science. (R. Giacomelli, J. Roy. Aer. Soc., Vol. 36, No. 259, pp. 578-597.) (24151 Great Britain.)

The author gives a concise summary and examples of insect and animal flight, and passes to an historical note on the development of theories of mechanical flight, with special reference to the work of Lanchester, Kutta, Joukowsky and Prandtl. In conclusion a note is given on Leonardo da Vinci's work.

A New Electrophotometer for Measurement of Turbidity of Liquids. (G. Gollnow, Z.V.D.I., Vol. 76, No. 19, 7/5/32, p. 466.) (24152 Germany.)

The light transmitted through the liquid falls on a photo-electric cell, and the current generated discharges a condenser. The rapidity of discharge is recorded on a stop watch as a measure of the turbidity.

Direct Sunlight in Interiors. (A. C. Stevenson, J. Sci. Insts., Vol. 9, No. 7, July, 1932, pp. 222-231.) (24153 Great Britain.)

Application is made of various map projections, of which the elementary geometry is discussed. Five projections are reproduced.

Nine references are given.

Equipment of Air Forces. (E. P. Warner, Aviation, Vol. 31, No. 6, June, 1932, pp. 247-253.) (24154 U.S.A.)

A descriptive account is given of the equipment of U.S. Air Forces, illustrated by 21 photographs of landplanes and seaplanes.

Brief performance data are given.

Congress Inquiry into National Air Defences. (Aviation, No. 6, June, 1932, p. 261.) (24155 U.S.A.)

A summary of the inquiry is given. A number of questions and answers are quoted. A useful review of the position of U.S. military aeronautics is given.

American Ordnance Depots in France. (G. S. Brady, Army Ord., Vol. 12, No. 71, March-April, 1932, pp. 309-314.) (24156 U.S.A.)

A brief descriptive account is given of the organisation of the Central Ordnance Repair Establishment at Mehun-sur-Yevre. Skilled men were obtained by private advertisement, the total staff reaching 12,000. Every branch of rifle and ordnance repair and munition supply was undertaken.

Aviation in Canada and the National Research Laboratories. (J. H. Parkin, Engineering Journal (Supplt. to J. Roy. Aero. Soc.), No. 2, Dec., 1931, pp. 17-23.) (24157 Canada.)

Statistical diagrams are given showing the growth of production, personnel, mileage, traffic, etc.

The second section of the paper gives a detailed account of the aeronautical equipment at the National Research Laboratory, Ottawa, including a free air-stream wind channel with a jet 9 feet in diameter, and a water tank 394 feet long by 9 feet wide by 6 feet deep.

REVIEW

Aviation and the Aerodrome

By H. Angley Lewis-Dale, M.B.E., M.Inst.C.E., M.I.Mech.E. (Chas. Griffin.) 15/-.

This book deals with the design and construction of aerodromes and also contains a quantity of useful information on the matter of aerodrome sites. It is, I believe, the only book so far published on this important subject.

It is clear that Mr. Lewis-Dale has been handicapped by limitations of space, as the book has to fit into the series of aeronautical text-books issued by Messrs. Griffin and Co., and under the circumstances he has wisely devoted the main portion of the book to the considerations which govern the choice of an aerodrome site—matters of drainage, planning and construction of hangars, nature and treatment of surface, petrol supply systems, etc. But such a book is incomplete without a comprehensive series of plans of modern aerodromes, with descriptions, so that the student can compare the different layouts. It is to be hoped that Mr. Lewis-Dale will be able in the future to write a more complete work on this subject.

In dealing with aerodrome surfaces, much space is usefully devoted to the subject of grass. While there is no doubt that grass-covered aerodromes will continue to be used for the less important cases, it is considered that the use of concrete runways, both for getting off and landing, will come more into use in the future for the large commercial aerodromes. Not only does the use of concrete largely reduce the upkeep expenses, but the use of concrete reduces materially the tractive resistance and shortens the time taken to take off. The tractive resistance offered by a grass surface differs seriously according to the weather, being very considerably greater when the ground is wet and soft. High tractive resistance had some advantage in the past owing to the help given to a machine in pulling up, but the introduction of wheelbrakes has nullified this advantage.

Mr. Lewis-Dale has written a very useful book which may be thoroughly recommended to all those contemplating the construction of an aerodrome.